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Human-Computer Interaction Design Principles for K-5 Digital Education

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Abstract

As more education is occurring digitally in K–5, providing quality digital instructional experiences has become integral to advancing learning outcomes. Students are spending more time online and are experiencing growing numbers of external digital distractions that cause attention to wane, self-regulation to be tested, and self-imposed interruptions to increase. To date, there is not a robust set of design principles for K–5 digital education that takes into account minimizing digital distractions and increasing attentional focus. This review examines the literature on attention, self-regulation, and digital distraction from this unique perspective and synthesizes a new set of nine Human-Computer Interaction (HCI) design principles for K–5 digital education from the different but related fields of Human-Computer Interaction, Instructional Design, and Children's Technology. These principles are unique because they focus on a K–5 population and are grounded in research on developmental differences of attention, self-control, and self-regulation. As such, these principles provide a framework for developing digital learning experiences that take into consideration the whole child, especially their developmental level.

Introduction

The K–12 education landscape has shifted rapidly over the past few years, placing more importance on digital education. Whether students and teachers are learning fully in-person, fully remote, or through a hybrid learning approach, the use of digital content in the classroom has increased 15% from 2016 to 2019, with 92% of K–12 school districts using digital instructional content (ASCD, 2019). Furthermore, the number of 1:1 device programs has doubled from 2016 to 2019, with 60% of districts in 2019 reporting they either have a 1:1 device program or have one planned in the near future (ASCD, 2019). When the global pandemic altered the K–12 landscape in 2020, 64% of students in the United States were learning either fully remote or through a hybrid approach in February 2021 (NCES, 2021). This rise in digital devices and use of digital instructional content, which occurred before the global pandemic and has only accelerated since, shows just how critical it is for digital instruction to be delivered to students in a manner that maximizes the desired student outcomes—especially given that students' attention can wane and succumb to digital distraction. For example, among college students, 49% of students reported that using digital devices in class for off-task use was distracting to them (Neiderman & Zaza, 2019). Another study found that students spent over 20% of class time using a digital device for non-class purposes, with the average student using it over 11 times (McCoy, 2016). Although the previous examples involved college-aged populations, students in a K–12 environment may have less ability to self-regulate (Enns & Brodeur, 1989) and need more guidance to remove digital distractions in order to focus on school work.

With the rise of digital device usage among students for both school work and non-school work, potential digital distraction can increase as students attempt to limit time on social media and non-school sites in an attempt to focus on school work. Although students may want to limit digital distraction, many have reported being unable to do so, and their academic performance has suffered (Dontre, 2021; Lindström, 2020). Several studies have examined the effectiveness of non-digital self-regulation strategies in a digital learning context such as awareness, restriction, and mindfulness, and all were ultimately found to be unsuccessful (Lai & Bower, 2019; Parry & le Roux, 2019). These findings point to the power of distractions in a digital environment and the need to explore interventions that are integrated directly into the digital environment. Therefore, another potential avenue to explore for reducing digital distraction for students is in the design of digital educational programs that can help keep students' attention focused on the task at hand.

Given that there is a large difference in susceptibility to distraction for students at either end of the K–12 spectrum (Gazzaley & Rosen, 2016), and given that there is a known relationship between digital distraction and attention (Bandura, 1986), students' developmental levels should be taken into account when designing digital educational tools. Special attention should be given to the K–5 population, considering the smaller capacity for attentional resources at a stage when students are learning so much about the world around them. To help students learn more effectively, designers of digital educational tools can take into account how students interact with their digital devices in this rapidly changing developmental time so that attentional resources can be best focused on educational work.

To limit digital distraction in K–5 students, Human-Computer Interaction (HCI) design principles should be applied to educational technology so that students' attention can remain focused on the task at hand. Researchers have documented HCI design principles that propose how digital interfaces should be effectively designed (Fuchs & Obrist, 2010; Nielsen, 1994a; Nielsen, 1994b). Some proposals have taken a holistic perspective considering that the user is situated in physical environments that influence their use of technologies. Fuchs and Obrist (2010) list several design principles from economic, political, and cultural areas, such as Efficiency, Freedom of Involvement, Participation in Decision Making, and Mental User Capacities in which users should have ease of use, simple user engagement, privacy, and enjoyment in their activities, respectively. Jakob Nielsen completed a factor analysis of 249 usability problems (Nielsen, 1994a) and derived a set of 10 heuristics for usability (Nielsen, 1994b), which are still applicable today. From a more psychological perspective, Dillon and Zhu (1997) argue that HCI design principles guide information perception and processing before any true instruction can occur. In the field of Instructional Design, Guney (2019) lays out standards for HCI design that include principles from User-Centered Design so that as much content on the screen can be as interactive as possible for refining different components based on user feedback. However, this should be considered in combination with the insight that Chiasson and Gutwin identified, which found that too much information on the screen at one time can be confusing for the user, especially for children (Chiasson & Gutwin, 2005). Chiasson and Gutwin (2005) detail several design principles for children's technology, including easy point-and-click interfaces, engaging characters who narrate words on the page, and meaningful icons with fewer distractions.

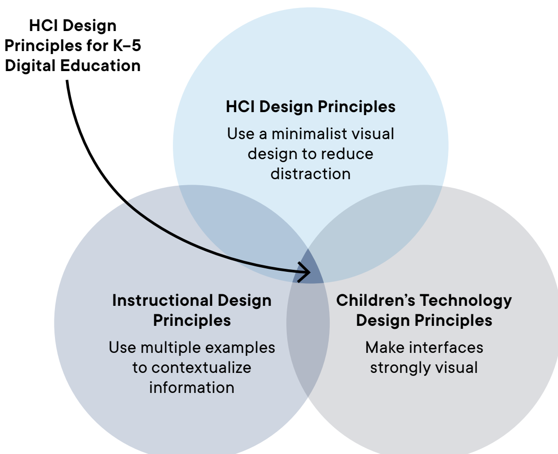

Figure 1: HCI Design Principles for K–5 Digital Education with examples from the three separate disciplines.

Design principles that encompass all three areas of HCI, Instructional Design, and Children's Design are spread throughout each discipline; however, when designers seek to minimize digital distractions that could be caused by children's limited attentional resources, an overlap of the principles from these three similar yet different disciplines must be combined for guiding designs for K–5 educational technology (Figure 1). The key to these design principles for children's educational technology is to reduce digital distractions so that attention itself can be focused on the task at hand and self-regulation is maximized where possible.

The goal of this paper is to present HCI design principles for K–5 digital education that enhance student engagement and advance learning outcomes by informing future design decisions. Through an examination of existing literature on attention, self-regulation, and self-control at various developmental stages, we synthesize the findings to propose a set of nine HCI Design Principles for K–5 digital education. This set of design principles builds upon the literature of the above-mentioned design principles rooted in the three different disciplines to provide a framework specific for the K–5 digital learning environment.

Theories of Attention

Most models of attention consider that people have a limited capacity for attentional resources. These models can be allocated either to a defined focused area (as in a zoom metaphor) or dispersed across a wider view (as in a telephoto metaphor). People can also be selective in their attention — an example is when they scan for specific information, they tend to ignore other information, leading to what is called inattentional blindness (Wood et al., 2006).

In designing for digital education, attention can be further considered in terms of sustained attention, attention shifting, and executive function (Kindlon, 1998). Sustained attention refers to the duration of attention, or the ability to maintain attention or vigilance on an object for a period of time (Kindlon, 1998). Attention shifting occurs when people switch their attention to different sources. When people switch attention among different tasks and activities, it is called multitasking. People perform worse on dual-task switching compared to working on each task sequentially (Wood et al., 2006). Executive function can be thought of as the "central coordinator" of the brain, as it governs processes of planning, impulse control, organized search, and goal-seeking behavior (Welsh et al., 1991).

Above all, attention is dynamic, influenced by the context, difficulty and nature of the task, and display of information. Attention has three levels of processing that change based on the task: skill-based (using fewer processing resources), rule-based, and knowledge-based (using more processing resources), depending on the requirements of the task. An example of skill-based processing is a routine task such as turning on a lamp. If the lamp does not turn on, then an individual will switch to rule-based processing, in which she tries a common strategy for solving the problem, such as making sure the lamp is plugged into the wall outlet. However, if the lamp still does not turn on, then she might apply knowledge-based processing, in which she uses more complex reasoning to troubleshoot the problem. For example, she may think that the light bulb is burned out, so she inspects it to determine whether it needs to be replaced.

Developmental Differences in Self-Regulation and Attention

In order to understand how attention and self-regulation affect the student learning experience, how attention and self-regulation develop throughout a student's life must be explored. To understand attention and self-regulation, we must explore not only digital traction but also digital distraction and how it can be experienced in the classroom and measured in a digital setting.

The relationship between attention and self-regulation has long been recognized, dating back to the 19th-century psychologist William James (Karoly, 1993). Self-regulation is believed to be a stable personality trait and is defined as the tendency to keep on track to follow goals (Karoly, 1993). In the context of digital education, it is important to consider it as a characteristic that enables individuals to have control over their actions and to avoid distractions (Karoly, 1993). Several behaviors fall under the umbrella term of self-regulation (or lack of, as in impulsivity): sensation or thrill-seeking, inhibitory control, decision time, persistence, failing to correct inappropriate responses, and distraction (Kindlon, 1998).

Self-Regulation

A classic study by Mischel et al. (1989) showed how the behavior of delaying gratification in children as young as four years old can predict future behaviors a decade later or even longer. In the study, performing self-control and delaying gratification is associated with higher future scholastic achievement, greater social responsibility, and stronger ability to resist temptation. In conditions when the rewards were exposed to pre-school children, seconds of delay time (i.e., waiting for the reward) significantly predicted SAT scores (Mischel et al., 1989). Furthermore, the study showed that children who had better self-regulation in later adolescence were judged to be better able to cope with personal and social problems. It is worth noting that a possible underlying covariate exists to explain the observed relationship (e.g., a more stable family environment) due to an unrepresentative sample used in the original study, yet correlations with higher academic achievement later in life are still present in the study by Watts et al., (2018). Given this, the findings suggest that self-regulation behaviors displayed in early years may have a relationship with future outcomes.

Developmental and individual differences have been found with attention and self-regulation (Best et al., 2013; Blumberg, 1998; Greenberg & Waldmant, 1993; Kopp, 1982; Tipper et al., 1989). To test developmental differences in inattention, impulsivity, information processing, and consistency, Greenberg and Waldmant (1993) administered an attention performance test, the Test of Variables of Attention, to 775 children, ages 6 to 16. In this study, the mean percentage of errors and mean reaction time — measures of inattention and impulsivity — decreased curvilinearly with a child's age, which suggests that attention and impulse control show rapid development early in childhood and then level off in later childhood and early adolescence. These results suggest that sustained attention and impulse control improve with age overall.

Attention

Developmental differences are also found with executive function (Best & Miller, 2010; Welsh et al., 1991; Wu et al., 2011; Xu et al., 2013). Welsh et al. (1991) found that different aspects of executive function mature differently throughout child development. In this study of 100 children, individuals ages 3 to 12 were given a series of six tests to measure executive function ability. The authors found that the attainment of adult-level competency in executive function varied by the type of task and that there are three stages of skill maturation for executive function: at ages 6, 10, and adolescence. A factor analysis of the measures in the study revealed three main factors of executive function: verbal fluency and motor sequencing; hypothesis testing and impulse control; and hypothesis generation. Drilling down deeper into other types of skills associated with executive function, the study showed that recognition memory achieves adult competency by age 4; however, at age 10, children attain an equivalence to adult competency for impulse control and visual search. Thus, this study shows that early prefrontal cortex skills, where executive function is based, develop in stages during childhood. As such, knowing the age of a student is critical to understanding their potential intellectual performance.

As mentioned, people have a limited capacity for attention. Research indicates that younger children are more prone to distraction, as they are more likely to misdirect their attention (Enns & Brodeur, 1989). Studies also suggest that children lack the strategies that adults use for allocating their limited attentional resources (Enns & Brodeur, 1989; Matusz et al., 2015; Wahn & König, 2017). Enns and Brodeur (1989) tested strategies used in covert orienting, locating specific targets in a field, to investigate how these strategies change throughout human development. As the study mentions, orientation of the visual system can be exogenous (e.g., through external stimuli such as a flash of light or sound), or endogenous (e.g., regularly referring back to instructions to stay on track). Enns and Brodeur (1989) tested 45 students in first grade, third grade, and university (average age 20) to see how their covert attentional ability changed with age. In the study, response time and accuracy to targets on a display were measured in a laboratory setting.

The results from Enns and Brodeur (1989) showed that younger children were able to perform covert orienting, identifying the specific objects in a field. The younger they were, the more often they misdirected their attention toward the wrong targets. In other words, children are drawn to peripheral targets, and the results suggest that they do this automatically. Additionally, these results from Enns and Brodeur (1989) suggest that younger children are slower to disengage from the wrong cue to focus on the correct cue when compared to older children. In other words, the cost of misdirecting attention is greater in younger children, as it takes them longer to refocus on the correct object. Furthermore, adults applied endogenous factors (e.g., a strategy of predicting where the cue would be) to react to the correct target, whereas younger children did not (Enns & Brodeur, 1989). In sum, this study illustrates how the allocation of attentional resources improves with age as the ability to ignore peripheral targets and orient the visual system develops.

Personality and Its Relationship to Self-Regulation and Attention

Several studies have shown that there are innate differences in attention and self-regulation for students with different personality types (Mark et al., 2016; Shiner & Caspi, 2003). Understanding these relationships can help not only in predicting self-regulation from personality types but also predicting personality types from measures of self-regulation (Azucar et al., 2018; Mark et al., 2016).

Childhood personality shows relative continuity through adolescence and adulthood, and personality traits stabilize and peak at age 50 (Shiner & Caspi, 2003). These authors have developed a taxonomy of measurable personality traits for children and propose, based on a review of years of measuring personality in children, the most robust traits to measure. These proposed personality dimensions can be measured beginning in pre-school and are as follows: Extraversion/Positive Emotionality, which measures sociability and dominance; Neuroticism/Negative Emotionality, which encompasses anxious and irritable distress; Conscientiousness/Constraint measures the capacity for cognitive, behavioral, and emotional control, of which Attention, Inhibitory control, and Achievement motivation are three subdimensions. Effortful control is also related to this dimension and refers to planning behavior, inhibiting responses, and focusing and shifting attention (Rothbart et al., 2001). Agreeableness measures prosocial behavior and cooperation, and finally, Openness to experience measures an individual's curiosity, creativity, imagination, and intellect (Shiner & Caspi, 2003).

When examining the relationship between personality and attention, people's online attention duration has been found to be related to the personality trait of Neuroticism from the Big 5 personality instrument described above (McCrae & Costa, 2008) and the personality dimensions of Impulsivity-Urgency and Impulsivity-Perseverance from the UPPS instrument (Whiteside & Lynam, 2001). In a study by Mark et al. (2016), the computer activity of 40 participants who worked as information workers was tracked over 12 days during the workday. The results showed that Neuroticism and Impulsivity-Urgency were inversely related to attention duration, whereas Impulsivity-Perseverance, another dimension of the UPPS, showed no significant relation. While the study was conducted with adults, further research could address whether in a study among children, higher scores on personality dimensions of Neuroticism and Impulsivity-Urgency may also be linked to a shorter attention duration on the computer.

Situational Factors

Situational factors also seem to influence attention. A study by Mark et al. (2016) looked at the stress and sleep patterns of 40 information workers in situ during a 12–day period and found that stress and sleep each showed a strong negative correlation with focus duration, and the results indicated that higher focus duration predicted higher self-assessed productivity. When the study further evaluated the effect of sleep in the context of personality traits, a factor analysis of the variables of Neuroticism, Impulsivity-Urgency, and Stress revealed they were all strongly associated with two broader factors: Lack of Control and Time Pressure. Of those two factors, only Lack of Control showed a significant negative correlation with focus duration in the study. In other words, the higher a person's lack of control, the shorter their focus duration. These results suggest that higher levels of Neuroticism, Impulsivity-Urgency, and Stress lead to shorter attention spans, and given that Neuroticism is largely unchanged over time, working to improve a child's self-regulation in learning (e.g., Schunk et al., 2007) and reducing stress where possible could lead to a higher duration of time spent on task.

Summary

Because different attention-related abilities, such as executive function and covert orientation, develop at different rates (Enns & Brodeur, 1989; Welsh et al., 1991), it is important to note these differences when designing features and products across the K–5 spectrum. When tasks require covert orientation, elements should be carefully evaluated for their ability to cause unintended distraction, especially when creating solutions used by students in grades K–3, as endogenous orientation skills have yet to be developed. Equally important, models that use measures of attention as inputs must take into account the age of a student, as evidenced by the variance in self-control and executive function at different ages. Any attempts to measure or predict attention should consider the impact of situational factors, such as stress, that may differ even for a single individual at different points in time (Mark et al., 2016). These findings give more credence to the HCI design principle of making interfaces strongly visual and limiting text to reduce stress and cognitive load (Druin et al, 2001).

Digital Distraction

Studies of digital distraction behavior draw on the aforementioned theory that humans have a limited capacity for attention and information processing (Bandura, 1986), and attending to the multiple sources of information available on computers can lead to cognitive overload (Sweller, 1994). Classical attention theory shows that when the demand for attention exceeds the human capacity for processing the information, then there is a decrease in performance (Broadbent, 1958; Treisman, 1964). Therefore, understanding how digital distraction manifests and how it relates to student outcomes can allow for digital educational designers to minimize distracting elements and help children focus their limited attentional resources on the educational tasks at hand.

A study by Yeykelis et al. (2018) using screen capture found that entertainment content held the longest online attention duration of all users of all ages. The authors applied a theory that people are of different motivation types, evoked from media stimuli: ASA, appetitive (i.e., approach) and DSA, aversive (i.e., avoidance). These types can occur independently, in unison, or in contradiction to each other, and they are theorized to affect people's task-switching behavior on the computer (Lang et al., 2007). Risk-takers score high in ASA and low in DSA, and risk-avoiders score low in ASA and high in DSA (Lang et al., 2005). People who are termed "coactives" are high in both systems, while "inactives" are low in both systems (Lang et al., 2005). When examining the relationship in the study by Yeykelis et al. (2018) between motivation types and time spent on content, the researchers found the following: Coactives spent the longest time on work content while risk-takers had the shortest attention span. Additionally, the study found that risk avoiders and inactives were lower on the number of switches and anticipated arousal. Therefore, this study suggests that knowing whether students score higher on the ASA and DSA scales could indicate whether a student is more likely to become distracted by digital stimuli.

In general, regardless of motivation type, people's attention duration is relatively short on any computer screen. Using computer logging, Mark et al. (2016) found the average attention duration to be 47.0 (sd=21.4) seconds for adult information workers. Yeykelis et al. (2018) found the mean length using screen capture to be somewhat longer, 70 seconds, while the median length was 11 seconds. In order to examine multitasking behaviors in students and the relationship to stress, Mark et al. (2014) used automatic logging of computer behavior and found that among college students, average attention duration was about 48 seconds (sd=16.47) on any screen before switching. The ten highest multitaskers (defined as screen-switching) switched 2.1 times per minute, and the ten lightest multitaskers switched .8 times per minute (Mark et al., 2014). Although these attention durations range from 47 seconds to 70 seconds, none of these average attention durations would suggest enough time for meaningful comprehension. When examining the relationship between multitasking and stress, Mark et al. (2014) found that participants who shifted their attention faster, as measured by more window switches, had higher reported stress levels. Therefore, when designing digital education platforms, it is important to note that student multitasking increases stress levels, and reducing digital distractions or limiting the ability to switch windows could substantially increase time-on-task and reduce stress.

Digital Distraction Behavior in Students

Although multitasking and generally distracted behaviors were present in many of the studies involving middle school and high school students, there are notable differences in the types of students who were more prone to distraction. Because few studies have been reported on digital distraction behavior in a K–5 population, findings from studies in older populations may provide insight into how digital distraction may affect students in younger populations.

A study by Rosen et al. (2013) examined digital distraction of students in a home environment while studying. In addition to providing a comprehensive review of how technological distractions affect learning, this study provides one of the most detailed views of students' minute-by-minute pattern of studying alongside technology. Investigating the behavior of 279 students in middle school (N=31), high school (N=124), and college (N=108), trained observers observed the students as they studied in their home environments. Observers noted minute-by-minute behavior over a 15–minute period, which included attention spent on schoolwork and attention spent on non-relevant schoolwork material (e.g., YouTube, music). These observations showed that students were on-task only 65% of the time, and students remained on task for an average of 5.61 minutes. When the results are broken down by grade levels, results show that high school students spent more time texting than middle school and college students, that middle school students played more video games than high school and college students, and college students applied more strategies for studying than middle school students even when controlling for overall time spent on devices and overall time-on-task. It is interesting to note from the results in this study that a preference for multitasking predicted off-task behavior using the Multitasking Preference Inventory (MPI) scale.

The limitations of the Rosen et al. (2013) study are that observations of the students were completed during a short period of time and that the observer could have affected the student behavior. For example, it is possible the presence of the observer in the study incited the halo effect, increasing the likelihood that a student would try to stay on task. Thus, it is possible that this study underestimates the distractibility of students and that in actuality, the average time-on-task may be even shorter than 5.61 minutes. In conclusion, off-task multitasking is associated with technological distractions in the learning environment, including texting and video games (Rosen et al., 2013).

Because not all learning occurs in a formal setting, the degree to which multitasking occurs during informal learning is important to understand. Judd (2013) examined student multitasking behavior in an informal digital learning environment and found multitasking to be quite prevalent, occurring at least once in over 70% of the observed sessions and occurring the entire session in 35% of all observed sessions. Judd defined focused activity as attending to one task for an uninterrupted 10 minutes, and only 30% of the sessions were found to be focused sessions. Compared to previous studies, this study shows that in the context of self-directed learning, students still multitask to a very high degree.

As smartphones have risen in prevalence and some schools move towards BYOD (Bring Your Own Device) policies, smartphone use is an important factor to consider in analyzing digital distraction. In a study examining smartphone use in classrooms, Kim et al. (2019)

looked at data from 84 university students over 14 weeks collected in classroom settings, controlling for contextual factors such as classroom attendance. They found that all but three students used their smartphones in 80% of their classes at least once, and students used their smartphones on average over 25% of the time while in the classroom. Students were distracted on average every three to four minutes, for an average of over a minute on their phones, with that time primarily spent using social media and messaging. It is important to note that students significantly underestimated their frequency of smartphone use when comparing self-reports to actual usage, sowing more doubt into the accuracy of self-reported data and showing the importance of unobtrusive measures in measuring attention, self-regulation, and digital distraction. The authors recommend that if students can regulate their smartphone use by first realizing how much their smartphones are being used, then brief smartphone use for planned breaks could have positive effects, and smartphones could add to the learning experience and not distract from it.

Digital Distraction and Its Relationship to Student Outcomes

Several studies have found that less time-on-task relates to lower performance on student outcomes (Bowman et al., 2010; Kuznekoff & Titsworth, 2013; Waite et al., 2018). A review by Kim et al. (2019) shows that performing off-task work while multitasking is detrimental to learning, with a consistent link between multitasking and lower student performance.

A widely cited study by Fried (2008) shows that the distractions from laptop use during a classroom experience hinder class performance. In this study, 137 college students were told they could bring their laptop to class, but it was not required for use in the class. In the study, students filled out weekly surveys in which they reported exactly how they used the laptop during class time (e.g., taking notes, playing games). Controlling for ACT scores, attendance, and high-school rank, the authors found that the more the students used their laptops, the lower their course grades. The results showed a negative correlation between laptop use and the amount of attention paid in lectures. Furthermore, the effect of using an optional laptop was also found to negatively impact the course grades of the students sitting near those students who chose to use laptops. Although the results may not transfer completely to a K–5 1:1 laptop environment where the use of the laptop may be mandatory for learning, it is important to be aware of the potential distractions that result from the use of a laptop.

One other factor that has been hypothesized to be related to internet overuse and academic performance is internet literacy (Torres-Díaz et al., 2016). Internet literacy refers to understanding how to use the internet to achieve work or personal goals (Coiro, 2003). In a study by Leung and Lee (2012), face-to-face interviews were conducted with a randomly chosen sample of 718 children and adolescents ages 9 to 19 living in Hong Kong. The survey focused on their internet use patterns, literacy, and academic performance, using self-reported measures of academic performance. The self-reporting was weighted by a measure of cognitive or academic competence to control for socially desirable responses that could be caused by a halo effect from the students telling researchers what they may think the researchers want to hear.

Respondents in Leung and Lee's (2012) study were asked how long they spent on various internet and social media activities. Results showed that scoring high on internet addiction, as measured by the prevalence of at least five of the eight criteria outlined in the DSM–IV: Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (American Psychiatric Association, 1994), is positively correlated with internet literacy and inversely correlated with academic performance. However, results also showed that internet literacy is positively related to academic performance. Because internet addiction itself is inversely correlated with academic performance, it follows that there are internet activities that cultivate digital literacy but do not also foster internet addiction. For example, internet addiction is more associated with internet activities for leisure, such as social media, than using email or browsing web pages (Chou et al., 2005). With internet literacy positively correlated with academic performance, finding a way to effectively improve students' digital literacy skills as part of the digital learning experience could lead to higher academic outcomes.

Since internet literacy has been shown to positively correlate with academic performance, researchers have explored the behaviors associated with productive internet use. Junco and Cotton (2012) investigated two interrelated research questions: 1) How often do students use ICTs (Information and Communication Technologies such as cell phones, laptops, and various software applications like social media or internet browsing) while doing schoolwork?, and 2) How does the use of ICTs relate to student outcomes? To answer these research questions, the researchers collected survey responses from 1,774 college students who were asked "on average" and specifically "yesterday" how much time they spent searching online for information, on Facebook, on email, using messaging, and on cell phones. The students' official college GPA was used as a dependent variable for measuring student outcomes.

With regards to the use of ICTs while doing school work, the Junco and Cotton (2012) study found that students reported spending about two hours per day searching for information online while studying. When examining how ICT use relates to student outcomes, the study found that even when controlling for high school GPA, only Facebook use and texting had negative correlations with college GPA, whereas emailing, searching for information, cell phone use, and messaging use while doing schoolwork were not correlated with college GPA. The authors explain that using ICTs while studying uses up cognitive resources, again pointing to the theory of limited attentional capacity, discussed earlier. This theory could explain why some ICT use negatively impacts GPA since the cognitive resources that could have been used toward academic work is instead going partially to non-academic activities, such as using Facebook and active texting. Therefore, knowing that students are spending roughly two hours per day on ICTs while studying, if proper internet usage were encouraged and multitasking were reduced, the negative effects seen in the study from overall internet use could be minimized and the benefits fully realized (Junco & Cotton, 2012). While K–5 students are unlikely to use multiple devices and ICTs in the same manner that college students do, they frequently access information across several browser tabs, learning apps, and from varied media sources. Knowing this, encouraging proper internet usage and encouraging educators and digital education designers to minimize digital distraction could lead to improved learning outcomes.

Despite several articles detailing the relationship between digital distraction and student outcomes in higher education, there have been no reported human-computer interaction studies detailing this relationship in a K–5 audience that do not use self-reported academic outcomes. As such, it should be noted that some of these results may not be directly applicable to a K–5 population, but the general trends are still revealing. This lack of reported research in a K–5 setting provides an opportunity for future research to be conducted.

Summary

Digital distraction can manifest in several different ways for students, and fewer distractions correlate with higher academic performance and lower stress levels (Leung & Lee, 2012; Mark et al., 2014). Given this information, designers of digital educational tools can include design elements to potentially reduce student stress and increase focus by continuing to develop tools that decrease the likelihood of multitasking and limit digital distractions. Having a way to lock a screen or prevent tab-switching during study could reduce potential digital distractions and therefore may lead to higher student outcomes.

Design Principles

Given the preceding literature on developmental differences in attention and self-regulation and the literature on digital distraction, we propose nine HCI design principles that should guide the development of digital educational tools in K–5 environments. These design principles incorporate the points raised previously in this review and are synthesized from existing design principles and heuristics from HCI, Instructional Design, and Children's Technology Design.

DESIGN PRINCIPLE #1:

Make objects onscreen interactable where possible, and highlight interactability with audio and visual cues when appropriate.

A study by Kirsh (2020) found that greater attention given to a word, as measured by a heat map based on cursor placement, could actually be associated with comprehension difficulties. Therefore, having more information that is interactable on the page would allow for more insights on readability to be discerned (Guney, 2019). Although making more items interactable can be effective for measuring what information is the object of attentional focus, it is also important to minimize the number of visual changes during reading tasks, especially as younger children require more time than adults to disengage from the wrong visual cue (Enns & Brodeur, 1989). The insight from Kirsh (2020) suggests that interactable content offers an opportunity to gather more information about a student's browsing experience; however, any feature that captures such information should minimize distraction to the student (Chiasson & Gutwin, 2005) while also upholding HCI design principles of privacy and ease of use (Fuchs & Obrist, 2010).

DESIGN PRINCIPLE #2:

Keep the design highly visual, and remove unnecessary elements wherever possible.

Children are more likely to become distracted by superfluous information on a screen, so to reduce cognitive load, as many elements should be removed from the design where possible (Chiasson & Gutwin, 2005; Nielsen, 1994b; Rosen et al., 2013). When tasks require covert orientation, elements should be carefully evaluated for their ability to cause unintended distraction, especially when creating solutions used by students in grades K–3, as endogenous orientation skills have yet to be developed (Enns & Brodeur, 1989; Welsh et al., 1991). These findings give more credence to the HCI design principle to make interfaces strongly visual and limit text to reduce stress and cognitive load (Druin et al., 2001).

DESIGN PRINCIPLE #3:

Take psychometric measurements as unobtrusively as possible.

Several existing valid and reliable psychometric measures can be used to validate the constructs of sustained attention, impulsivity, and self-regulation with a K–5 population (Dougherty et al., 2002; Greenberg & Waldmant, 1993; Luszczynska et al., 2004; Scarpina & Tahini, 2017; Welsh et al., 1991). The advantage of using unobtrusive measures of attention is that they provide continual, longitudinal, and precise measures of the user's activity without placing a burden on the user (Webb et al., 1999). Further, objective measures are not subject to bias, as self-reports might be. Lastly, unobtrusive measures can be done "in the wild" in users' naturalistic settings, which has ecological validity (Webb et al., 1999). Digital educational designs should therefore embed these measurements into the programs themselves wherever possible to reduce adding digital distraction elements from the measurement tools themselves.

DESIGN PRINCIPLE #4:

Give feedback to students as quickly as possible with clear text, audio, and visual language.

Children expect an immediate response following an input, and if they do not receive a response either by sight or sound, they may continue to give the input until a response is received (Chiasson & Gutwin, 2005; Said, 2014). Therefore, a digital interface should give clear visual or auditory feedback related to the input given so students can more easily learn how to use the digital system (Chiasson & Gutwin, 2005; Druin, 2001; Nielsen, 1994b).

DESIGN PRINCIPLE #5:

Request confirmation from students before submitting responses, and let students easily modify responses.

Because younger children are still developing their motor skills, mistakes can happen more frequently. Therefore, making it easy for students to undo an action is necessary for students to have a positive experience with a digital interface. Because mistakes can happen, having students confirm the submission of an entry allows them to undo a selection if a mistake is made. These confirmation requirements can be lessened as motor skills develop into middle school and high school, but allowing students to undo easily remains an important principle whenever designing for K–5 (Chiasson & Gutwin, 2005; Druin, 2001; Nielsen, 1994b).

DESIGN PRINCIPLE #6:

Make mouse and touch-screen interactions simple with a minimal number of clicks.

Adding more clicks and drags in order to enter a command can unnecessarily increase the cognitive load on students; therefore, reducing the number of clicks can decrease the potential distractions that a student may encounter during the overall learning process (Chiasson & Gutwin, 2005; Druin, 2001).

DESIGN PRINCIPLE #7:

Avoid open-text responses in favor of selecting commands.

Students' cognitive load should be focused on the learning experience itself and not on navigating the digital interface. As such, steps should be taken to minimize the amount of cognitive load exercised when interacting with the digital interface. An effective way to minimize the cognitive load in the design of a digital system is to enable commands that are clearly understood (Nielsen, 1994b). For example, have students select a check mark or the word "YES" instead of having students type in "Y-E-S" to confirm a selection (Nielsen, 1994b).

DESIGN PRINCIPLE #8:

Avoid using keyboard shortcuts where possible.

Younger children have yet to develop their fine motor skills. Designers should not expect children to be able to complete complicated combinations of mouse clicks, such as a double-click, and keyboard combinations, such as holding shift for a capital letter. As motor skills develop over time, any mouse, keyboard, or voice shortcuts should be explicitly taught to students within the interface and should not be assumed to be known (Chiasson & Gutwin, 2005; Nielsen, 1994b). Keyboard shortcuts may be necessary to complete certain tasks for accessibility purposes and care should be taken in the design of shortcuts to avoid overly complicating them for children in the K–5 population.

DESIGN PRINCIPLE #9:

Reduce the use of extensive menus and submenus.

The extensive use of menus and nested submenus creates the susceptibility for too much distraction and cognitive load on the screen when students are deciding what commands to input. Thus, the recommendation would be for commands to appear on a sidebar when hovered over or selected, keeping the webpage design cleaner. (Chiasson & Gutwin, 2005; Druin, 2001; Nielsen, 1994b).

Conclusions and Future Work

Given what is currently known about students' levels of attention, self-regulation, and digital distraction in different environments, the nine HCI design principles for K–5 digital education that can be used by designers and educators alike are summarized in **Table 1**.

The specific design principles delineated above come from a variety of sources and may not apply or be possible in every situation. For example, a math lesson on fractions may require the calculation of the least common denominator, so providing the number as a selectable field for recognition may not be the best instructional choice despite its ease on students' cognitive load. In this instance, students should be expending cognitive resources to solve the problem; however, the cognitive load required to figure out the interface itself should be minimized.

It should also be noted that distraction does not come solely from the digital environment but also a user's physical environment. Although designers of digital educational systems cannot control the physical environment surrounding a student's computer, designers can provide students clear instructions within the learning system itself to clear their physical work space of clutter or limit nearby physical distractions, such as magazines, TV, and phones (Junco & Cotton, 2012). Creating a better overall environment to promote learning and limit distractions has been shown to reduce multitasking (Rosen et al., 2013), and reducing multitasking has been shown to increase student outcomes (Leung & Lee, 2012). Providing such a reminder to students to clear the physical workspace can nurture a behavior associated with highly engaged students: taking ownership of one's own learning experience (Aguilar, Sheldon, Ahrens & Janowicz, 2020). While more studies need to be completed looking at digital distraction specifically in a K–5 student population, the trends from self-reported metrics and studies in higher education show promising results that digital designers should take into consideration.

Because digital literacy has a relationship to digital distraction and is correlated with higher student outcomes (Junco & Cotton, 2012; Leung & Lee, 2012; Torres-Díaz et al., 2016), digital literacy in children should be encouraged by digital educational systems. When designing interfaces for a K–5 audience, designers should encourage good digital practices and good digital citizenship (Ribble et al., 2004) as part of the overall system design. Encouraging these behaviors can be an undercurrent that runs in parallel with high-quality HCI design, and systems that encourage digital literacy could be related to higher student outcomes in both the short term and the long term.

As designers of digital educational systems for a K–5 audience seek to use these combined principles, it should be noted that simple designs with judicious use of empty space can provide fruitful learning experiences for young children by keeping their attention on a small number of on-screen visual objects that quickly move or play sounds only when students are meant to interact with them. For example, when a student inputs an answer and hovers their mouse over the submission button, it could play a sound and slowly pulse to draw students' attention to it to signify that pressing that button will advance the learning tool. However, when a submission is not needed, the submission could either not be present on the screen or could not make a sound or pulse when the mouse hovers over it.

Digital interfaces continue to evolve with technology. The specific instances in which these principles themselves manifest can change, but the theory behind these principles for reducing digital distraction, keeping attention, and managing self-control will still be relevant. As circumstances evolve over time with digital learning, designers should keep these principles in mind regardless of the medium through which digital education is delivered.

TABLE 1:
A SYNTHESIS OF HUMAN-COMPUTER INTERACTION DESIGN PRINCIPLES FOR K-5 DIGITAL EDUCATION

1. *Make objects onscreen interactable where possible, and highlight interactability with audio and visual cues when appropriate.*
2. *Keep the design highly visual, and remove unnecessary elements wherever possible.*
3. *Take psychometric measurements as unobtrusively as possible.*
4. *Give feedback to students as quickly as possible with clear text, audio, and visual language.*
5. *Request confirmation from students before submitting responses, and let students easily modify responses.*
6. *Make mouse and touch-screen interactions simple with a minimal number of clicks.*
7. *Avoid open-text responses in favor of selecting commands.*
8. *Avoid using keyboard shortcuts where possible.*
9. *Reduce the use of extensive menus and submenus.*

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