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Evidence-based guidelines for the informal use of computers by children to promote the development of academic, cognitive and social skills

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The use of computers in the home has become very common among young children. This paper reviews research on the effects of informal computer use and identifies potential pathways through which computers may impact children's development. Based on the evidence reviewed, we present the following guidelines to arrange informal computer experiences that will promote the development of children's academic, cognitive and social skills: (1) children should be encouraged to use computers for moderate amounts of time (2–3 days a week for an hour or two per day) and (2) children's use of computers should (a) include non-violent action-based computer games as well as educational games, (b) not displace social activities but should instead be arranged to provide opportunities for social engagement with peers and family members and (c) involve content with pro-social and non-violent themes. We conclude the paper with questions that must be addressed in future research.

Practitioner Summary: This paper reviews research on the effects of informal computer use on children's academic, cognitive and social skills. Based on the evidence presented, we have presented guidelines to enable parents, teachers and other adults to arrange informal computer experiences so as to maximise their potential benefit for children's development.

Keywords: computers; games; Internet; cognitive, academic and social skills; informal computer use

1. Introduction

Digital tools such as computers and the Internet have become an integral part of young children's lives in many parts of the world. In 2009, among 8–18-year-olds in the USA, 93% reported having a home computer, with an average of two computers at their home, and 87% lived in a home with at least one video game console (Rideout, Foehr, and Roberts 2010). The rates of computer diffusion are similar in other industrialised countries: 87% of 9–19-year-olds in the UK (Livingstone and Bober 2005) and 91% of Australian households with children under 15 years of age (Pink 2009) reported having a home computer. In an international study of six major world cities, the percentages of 10–11-year-olds who reported having their own computer were as follows: Tokyo (12.8%), Seoul (27.7%), Beijing (39.7%), Helsinki (35.9%), London (55%) and Washington, DC (46.8%) (Benesse Educational Research and Development Center 2006).

Most youth in these countries also have access to the Internet and mobile devices; in the USA, 93% of 12–17-year-olds were online (Jones and Fox 2009) and 79% of 13–19-year-olds had a mobile device (Harris Interactive 2008). In the UK, 75% of 9–19-year-olds were online and 81% had a mobile device (Livingstone and Bober 2005); in Australia, access to the Internet was slightly lower, at 72% for all households, and 86% for households with children under 15 years of age (Pink 2009). Equally important, youth spend a significant amount of time with media; for instance, US youth (8–18-year-olds) report spending approximately 7 h 38 min per day with media; because they use multiple media at the same time, they actually consume about 10 h 45 min of media content per day (Rideout, Foehr, and Roberts 2010). Although children continue to spend the greatest amount of time with television and music/audio content, time with computers and video games is increasing. The 8–18-year-olds in the Kaiser study reported that they used the computer for 1 h 29 min per day to go online and access various applications and games for non-school-related purposes; they also reported that they spent an average of 1 h 13 min per day playing games on a variety of platforms (e.g. consoles, hand-held systems and so on). Use of computers is also increasing among very young children. In a survey of US children and their parents, 70% of 4–6-year-olds, 48% of children under 6 years and 11% of children under 2 years were reported to have used a computer (Rideout, Vandewater, and Wartella 2003).

As technology has become an integral part of young children's lives, there are many questions about the impact of computer use on their development (Straker et al. 2009). In this paper, we present evidence about the effects of children's informal computer use on the development of their academic, cognitive and social skills. Our use of the term 'informal computer use' draws from the terms 'informal education' and 'informal learning', which refer to the education and learning that occur outside of formal school settings (Greenfield 2009). In a similar vein, we define informal computer use as the

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normal day-to-day unstructured use of computers such as playing computer games or surfing the Internet. Although such use typically occurs within informal settings like the home, library or a museum, it can also occur during unstructured play time in classrooms and in after-school programmes.

To identify empirical evidence about the effects of children's informal computer use on their development, we systematically reviewed the literature by conducting searches on the PsychInfo and ERIC databases as well as www.scholar.google.com; search keywords included 'children, computers, cognitive development', 'children, computers, social development' and 'children, computers, skill/learning/effects'. Searches were done in 2010 and 2012 and yielded ~160 sources including published journal articles and chapters as well as online surveys and reports. These sources were reviewed carefully by both authors to identify articles that focused on typically developing children's informal computer use and that described studies on the relation of such use to their development. We excluded descriptive case studies as well as research on the use of technology as part of the classroom curriculum; some studies refer to such use as computer-assisted instruction (or CAI) and define it as the structured and formalised use of computers and software as part of the classroom curriculum (for recent reviews of such use, see Glaubke 2007; Lieberman et al. 2009; McCarrick and Li 2007; Schmidt and Vandewater 2008). We also only included research on typically developing young children up to the upper end of middle childhood (11 years); however, where relevant, we included sources that described studies with special populations (e.g. low-income, dyslexic children and so on) as well as adolescents and adults.

Using these criteria, we selected ~65 sources for inclusion in our review of the research on children's informal use of computers and the relation of such use to their academic, cognitive and social skills. To present the evidence from our review, we adopted a 'pathways of influence' approach (Subrahmanyam 2009; Subrahmanyam and Greenfield 2011), which identifies some potential paths through which the use of computers may impact the development of children's academic and cognitive skills (Figure 1) as well as their social skills (Figure 2). Such an approach emphasises that

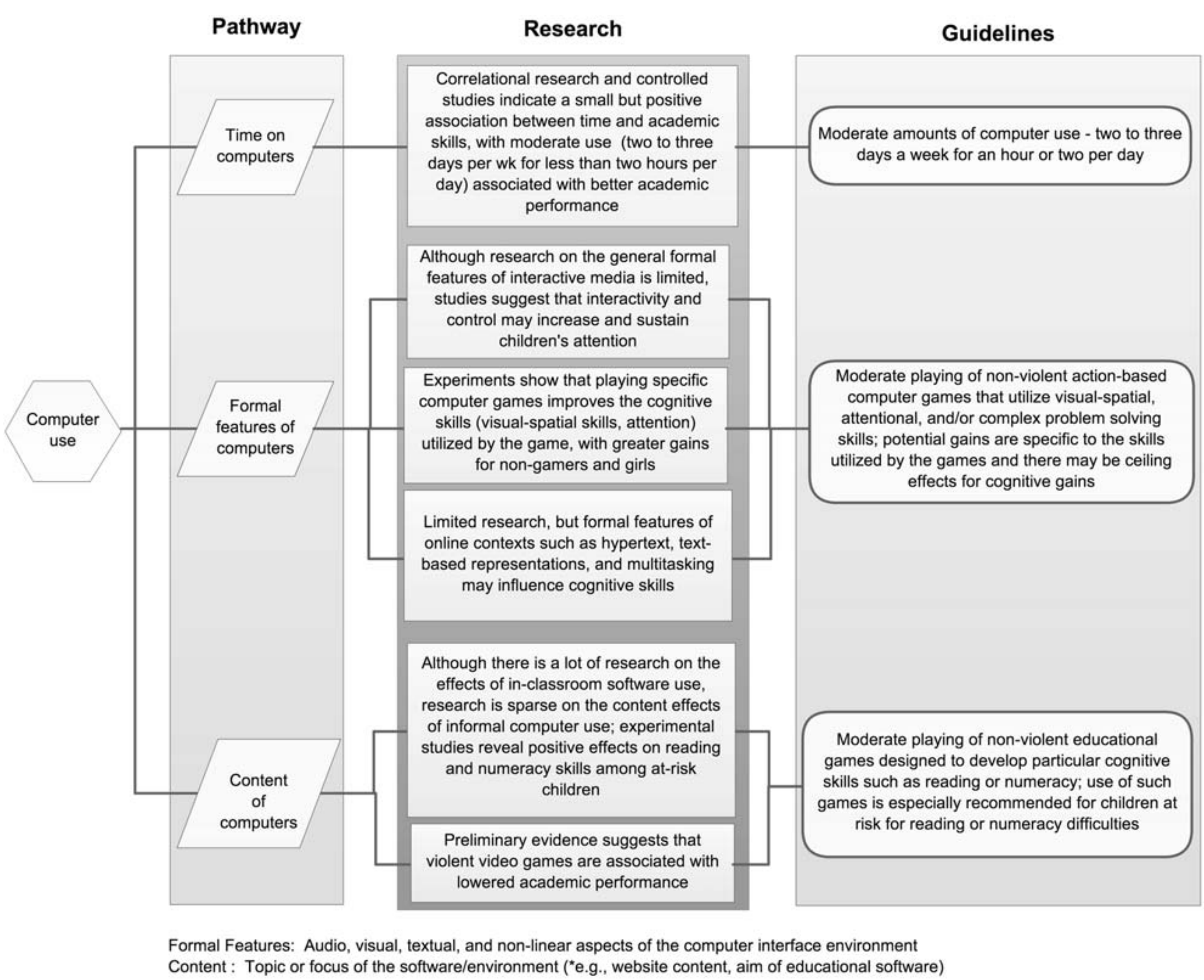

Figure 1. Children's computer use and the development of academic and cognitive skills.

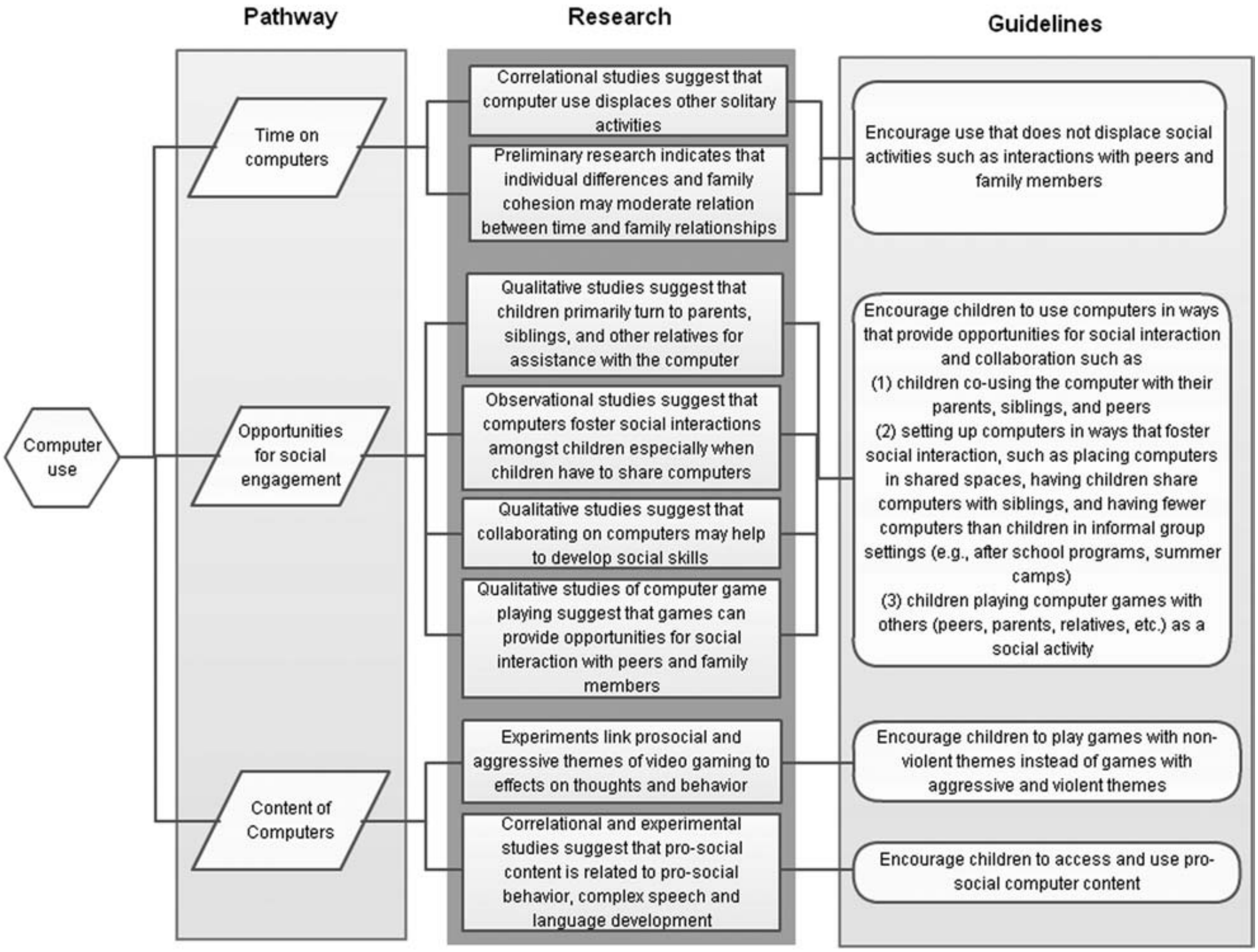

Figure 2. Children's computer use and the development of social skills.

computers are not monolithic and that different aspects of computers and different kinds of use contribute in different ways to mediate the impact of computers on children's skills. For each set of pathways (for academic and cognitive skills as well as social skills), we briefly review extant research, synthesise their main findings and provide guidelines for the wise use of computers by children based on this evidence. Straker et al. (2009) have pointed out the importance of having child-specific guidelines for the wise use of computers by children, and evidence-based guidelines to promote children's physical development were presented in a subsequent paper (Straker et al. 2010). Our guidelines are summarised in Table 1 – the notations (*, ** and ***) next to each guideline indicate our judgement and opinion of the strength of the evidence based on a review of the study's design and results. Correlation and survey studies that provided evidence that computer use and children's skills were associated were assessed as being the least strong and are indicated by (*). Interventions and experimental studies where the researcher manipulated computer use and controlled extraneous variables were assessed as providing stronger evidence for a causal relation between computer use and children's skills and are indicated with (**). Finally, studies using meta-analysis, a statistical technique that combines the results of several different studies, were judged as providing the strongest evidence and are indicated with (***). These evidence-based guidelines should enable parents, teachers and other adults to arrange informal computer experiences that maximise their potential benefit for children's academic, cognitive and social skills.

2. Children's computer use and the development of academic and cognitive skills

To understand the academic and cognitive implications of children's use of computers, we turn to Vygotsky's (1978) theory that cognitive development occurs in a socio-cultural context and is mediated by the tools provided by the culture. Tools elicit and develop different sets of skills and thus influence thinking and learning as well as development (Subrahmanyam

Table 1. Guidelines for the informal use of computers by children.

1.1.*	Encourage moderate amounts of time on computers; discourage minimal and excessive use, especially extreme amounts of time spent playing video games
1.1.1.*	Encourage moderate use – two to three days a week for an hour or two per day
1.1.2*	Encourage daily use of computers to not exceed 2 h per day
1.2**	Encourage moderate playing of non-violent action-based computer games that use visual spatial and attentional skills, and complex problem solving
1.3**	Encourage use of educational software
1.3.1.**	Select educational software that are designed to develop the particular skills (e.g. numeracy and reading) that are of interest
1.3.2.**	Encourage the use of educational software for children-at-risk for reading or numeracy difficulties
1.4.*	Monitor the use of computers so that it does not displace social activities such as interactions with friends and families
1.5*	Encourage children to use computers in ways that provide opportunities for social interaction and collaboration
1.5.1.*	Encourage children to co-use the computer with their parents, siblings and peers
1.5.2.*	Set up computers in ways that foster social interaction such as placing computers in shared spaces, having children share computers with siblings and having fewer computers than children in informal group settings (e.g. after school programmes and summer camps)
1.5.3.*	Encourage children to play computer games, including online games with others (peers, parents, relatives, and so on) as a social activity
1.6.***	Encourage children to play computer games with pro-social and non-violent themes and avoid games with aggressive and violent themes

Notes: *Correlational, regression, survey and/or qualitative studies. **Experimental and intervention studies. ***Meta-analytical reviews.

and Greenfield 2008, 2011). Computers, games and the Internet are the newest cultural tools in technological societies, and Subrahmanyam and Greenfield have identified at least three potential pathways through which they can influence the development of children's thinking (Subrahmanyam 2009; Subrahmanyam and Greenfield 2011). The first pathway is based on the idea that time with computers represents not only time spent on that particular activity, but also time taken away from other activities such as reading or homework that are valuable for the development of academic and cognitive skills – a notion referred to as the time displacement hypothesis (Nie and Hillygus 2002; Straker et al. 2009).

The second and third pathways stem from fundamental aspects of interactive media – their *formal features* – which include the audiovisual production features that characterise a medium, and their *content*, which is the topic or focus of a game or online site (Subrahmanyam and Greenfield 2008). Note that the form and content are distinct from the actual *physical platform or hardware* (i.e. television, computer or video game system) of a particular medium. Accordingly, the second pathway of influence is via the formal features of computers, which are the symbolic and representational systems that they use, for instance, enactive (action-based), iconic (image-based) or symbolic (symbol-based) (Bruner, Olver, and Greenfield 1966), and that the user has to decode to grasp the message. Repeated use of a media form will lead to internalisation of the particular skills used by it, and over time will enhance those particular representational skills (Salomon 1979). The third pathway of influence is through *media content*, which consists of the message delivered by the formal features. With regard to computers and games, content could involve a particular topic area or theme such as maths, history or science. Next, we examine how the use of computers mediates children's academic and cognitive skills through each of the three pathways of influence (see Figure 1); then we present our recommendations based on the strength of the available evidence.

2.1. Time on the computer and academic and cognitive skills

The first pathway of computer influence is through the time that children spend on computer-based activities relevant to academic and cognitive skills and the activities that such use displaces. Since children often use multiple media at the same time, it is difficult to obtain exact estimates of time displacement. Nonetheless, the evidence to date suggests that computer use may primarily displace other screen-based activities (Attewell, Suazo-Garcia, and Battle 2003; Hastings et al. 2009; Hofferth 2010). Attewell, Suazo-Garcia, and Battle (2003) reported that 4–13-year-old children living in homes with and without a computer spent similar amounts of time on non-computer activities such as reading, sports or outside play. Based on an analysis of data from a survey of 6–12-year-olds in the USA, Hofferth (2010) reported that more time spent on the computer (playing, studying or communicating) was not associated with reduced time spent on off-screen reading; interestingly, more time spent studying on the computer was associated with more time on off-screen reading. Although the time spent on the computer for studying and communicating was not associated with non-screen study time, more time on computer games was associated with reduced non-screen study time (Hofferth 2010).

Correlational studies on the relation between home computing time and academic performance (e.g. scores on mathematics, reading and language arts) have yielded small but positive associations (Attewell, Suazo-Garcia, and Battle 2003; Borzekowski and Robinson 2005; Fish et al. 2008; Li and Atkins 2004; Van Scoter 2008). However, more time with computers is not necessarily associated with better academic performance. Fish et al. (2008) reported that moderate use (weekly) was associated with better performance as compared with both infrequent (monthly or less) and excessive (daily) use; Hofferth (2010) found academic benefits for children who used the computer at low (< 1 h 40 min per week) and moderate rates (< 6 h per week) with greater gains for African-American children. The relationship between home computing time and academic performance is also moderated by what children do when they use computers. For instance, Hastings et al. (2009) reported that time spent playing video games was negatively related to school competence and Jackson et al. (2011) found that time spent online was associated with better reading skills, whereas playing video games was associated with lower grade point averages.

In a longitudinal study of 4983 Australian 5–7-year-old children, positive correlations were found between computer time and measures of school readiness (the *Peabody Picture Vocabulary* and the *Who am I* tests) after controlling for factors such as school type, child activities and extracurricular activities, as well as household demographics. Children's gains from their time on the computer at Time 1 remained two years later, and larger gains were found for computer time during the weekend, for girls and for children with two working parents (Fiorini 2010).

The strongest evidence for the academic benefits of informal computer use comes from controlled studies with low-income children (Li, Atkins, and Stanton 2006) and struggling readers (Karemaker, Pitchford, and O'Malley 2010). Li, Atkins, and Stanton (2006) investigated the use of developmentally appropriate software (e.g. *Millie's Math House*, *Bailey's Book House*, *Sammy's Science House*, *Thinkin' Things 1*, *KidPix* and *Dr. Seuss's ABC*) by 3–5-year-olds in a programme for low-income children. They found that daily use of the software for 15–20 min significantly enhanced school readiness and intelligence and that these effects were obtained over and beyond the effects of the programme curriculum alone (Li, Atkins, and Stanton 2006). Similarly, Karemaker found greater gains in reading ability among 5–6-year-old struggling readers who used the *Oxford Reading Tree for Clicker* as compared with a Big Book Printed format (Karemaker, Pitchford, and O'Malley 2010).

The research to date suggests a curvilinear relationship between children's computer time and academic and cognitive skills, and both excessive and minimal computer use have a more detrimental effect (Fish et al. 2008; Hofferth 2010). Determining the amount of daily computer time that is appropriate for children is not easy, given the changing nature of interactive technologies and the possibility that more computer time may be beneficial for low-income and other at-risk children. In the context of physical development, Straker et al. (2010) have recommended that children should use screen-based media for a maximum of 2 h per day. We concur with this recommendation, but note that it may need to be revisited as mobile and touch-computing devices (e.g. iPad, iPhone, interactive books and so on) proliferate.

2.2. *Formal features of computers and academic and cognitive skills*

The second pathway of influence on academic and cognitive skills takes into account the formal features of a medium, which are the enactive, iconic and symbolic representational systems that it uses (Bruner, Olver, and Greenfield 1966); because users have to decode this 'language' when using a medium, repeated use can have effects on their representational skills (Salomon 1979). This is akin to how computers are treated as analogous to the human brain in information processing theory. In this section, we first present research pertaining to the academic and cognitive effects of the general formal features of interactive media such as software, computer and video games and online contexts. We then present research on the effects of the formal features specific to computer games. Finally, we examine the research on the formal features of online contexts that could have important implications for academic and cognitive skills.

2.2.1. *Formal features of interactive media*

The formal features of most interactive media (e.g. computers and games) include features for navigation, such as the mouse to point and click on the screen, keyboard to execute commands and auditory and visual representations. According to the 2003 Kaiser Report, 64% of 4–6-year-old children know how to use a computer mouse to point and click and are in effect integrating their enactive representations using the mouse with the icons and iconic representations they find on the screen (Rideout, Vandewater, and Wartella 2003). By kindergarten (5–6 years of age), children are capable of navigating the mouse to click on very precise objects on the screen, as well as for drag and drop manoeuvers (Donker and Reitsma 2007); in one study, 3-year-old children were able to learn to use the mouse in 5 days (Revelle and Strommen 1990). An important question for future research is whether the particular computer input device used, such as a mouse or a touch screen, might mediate how toddlers and very young children access and process the representations (e.g. icons and text) on the computer.

Since computers make use of both auditory and visual modalities, practice with its text-based and auditory representations may contribute to the development of emergent literacy (early reading and writing that serve as a precursor to conventional literacy) and reading (Subrahmanyam and Greenfield 2008). Most of the studies on the effect of reading software on beginning readers have compared computer-assisted instruction with teacher-led reading instruction in a classroom context and are not reviewed here. But two points are worth noting about this body of work: first, extant studies on the effectiveness of reading software on specific reading skills (e.g. phonological awareness and text reading fluency) have found ‘a positive, though small, effect on beginning readers’ (Blok et al. 2002, 121). Second, research has not systematically isolated the effect of computer-based text versus auditory representations on children’s emergent and subsequent literacy skills.

Another important aspect of interactive media use is the ability for the user to actively manipulate his or her computing experience. A few studies have specifically examined the potential effects of interactivity in the context of reading software, and we consider them here (Wood 2005; Wood, Pillinger, and Jackson 2010). Using a sample of 6-year-old beginning readers, Wood, Pillinger, and Jackson (2010) compared the benefits of a phonics-based ‘talking book’ software used on the computer with one-on-one reading with an adult (who was not their teacher) using a paper version of the same book. Although the study was conducted in a classroom, the 15-min reading sessions on both the computer and with the adult mimicked the informal use of computers that is the focus of this paper. The authors reported that children in the talking book condition who were engaged but silent during the book reading session showed greater improvement in phonological awareness as compared with children in the tutor-led condition, who were more likely to repeat what the adult said or chime in when they knew a word.

Calvert, Strong, and Gallagher (2005) explored pre-school children’s (3–4-year-olds) attention and learning from a story presented on the computer by manipulating whether the child or the adult was in control of the computer software. Having control did not have an effect on children’s memory of visual or verbal content, but was effective in increasing their attention and interest (Calvert et al. 2005). More research is needed to understand the role of interactivity and control in sustaining children’s interest in screen-based representations and the cognitive implications stemming from long-term use as a result of such increased interest.

2.2.2. *Formal features of computer games*

Playing games is one of the primary computer-based activities that children engage in (Rideout, Foehr, and Roberts 2010; Vekiri and Chronaki 2008). Like video games, many computer games are action based, spatial, iconic, dynamic and have multiple things occurring simultaneously at different locations on the screen; because many of these features are common to computer applications of all kinds, the set of skills that the games develop constitutes a foundational computer literacy (Subrahmanyam and Greenfield 2011). The literature on gaming has not distinguished between games played on the computer and those on game consoles such as the GameCube or PlayStation. Accordingly, we briefly discuss this latter body of work since it is likely that the effects stemming from the formal features of a game will accrue, regardless of the particular hardware (computer or game system) on which it is played. Research has suggested that playing an electronic game can have positive effects on cognitive skills such as spatial cognition (De Lisi and Wolford 2002; Lager and Bremberg 2005; Okagaki and Frensch 1994; Subrahmanyam and Greenfield 1994), attentional skills (Dye, Green, and Bavelier 2009a; Tahiroglu et al. 2010) and visual processing speed (Dye, Green, and Bavelier 2009b). Although some of the studies mentioned earlier were based exclusively on data from children (e.g. De Lisi and Wolford 2002; Subrahmanyam and Greenfield 1994), others included data from children as well as adolescents and young adults/college students (e.g. Dye, Green, and Bavelier 2009a; Lager and Bremberg 2005; Okagaki and Frensch 1994). Interestingly, children with less prior experience in playing computer games achieved more short-term gain from such brief training (Subrahmanyam and Greenfield 1994; Tahiroglu et al. 2010), suggesting that there may be ceiling effects for cognitive gains from playing computer games.

Also relevant here are studies that have used computer-based training to enhance specific cognitive skills such as executive functions and attention among typically developing children. Although not the same as electronic games, the training uses tasks similar to those used in electronic games; for example, in a study by Rueda et al. (2005), training programmes required children to control an animated cat using a joystick, predicting where the cat would move to based on its initial trajectory, resolution of conflict and so on. Rueda et al. (2005) found that the computer-based training was effective in improving 4-year-olds’ executive attention skills as measured by behavioural scores and event-related potentials. In addition, the training produced significant increases in overall IQ, attributed to the increased executive attention ability (Rueda et al. 2005).

In another study, computerised training was effective at improving visual spatial working memory but not inhibition (Thorell et al. 2009). The training tasks for visual spatial working memory required children to remember the order and spatial locations of objects that would appear on the screen; for inhibition, the tasks required inhibitory responses such as inhibition of a prepotent motor response, stopping an ongoing response and interference control (for details of the tasks, see Thorell et al. 2009, 971). The researchers reported that 4–5-year-old children improved in both visual-spatial and verbal working memory, although only visual-spatial working memory was targeted (Thorell et al. 2009).

In the world of computer literacy, iconic representation is very important for navigating digital and virtual spaces, and video games have been shown to improve iconic representation skills in college students (Greenfield, Brannon, and Lohr 1994). Skills developed from certain video games may be relevant for real-world tasks (Greenfield 2009); for instance, computer simulators may be beneficial in the early stages of training airplane pilots (Dennis and Harris 1998). Finally, the formal features of action games may also help to develop complex problem-solving skills. In a review of digital games, Hsiao (2007) highlighted the complex and challenging tasks that gamers have to learn and become proficient at in order to win the games and has proposed that games provide opportunities for learning and help to develop problem-solving skills as players advance through the game. In addition, spatial abilities (which are shown to be enhanced by game playing) are also important in developing problem-solving skills (Lager and Bremberg 2005).

2.2.3. *Formal features of online contexts*

In terms of formal features, online contexts such as websites contain text and audio-visual representations displayed through hypertext, which makes it possible to access other content by clicking on links within a page. In addition, the Internet enables multitasking, which is the use of multiple applications (e.g. Internet and word processing applications) or multiple windows of the same application (e.g. multiple instant message windows) at the same time. Although research is sparse on the effects of the Internet's symbol systems on the development of cognitive skills, Subrahmanyam and Greenfield (2008) have speculated that the use of the Internet is most likely to have an impact on verbal and spatial representational skills. Here, we briefly consider these possibilities in turn.

With regards to text-based representations on the Internet, online information applications such as websites largely require comprehension of text and audio, whereas communication applications (e.g. email and instant messaging) require both the comprehension and production of text and audio. In this regard, research suggests that the text-based representation of the Internet may support emergent literacy and problem-solving skills, and thus may facilitate conceptual development. For instance, McPake, Stephen, and Plowman (2007) reported significant differences in expressive language, metacognition, visual perception and auditory memory between children who engaged in online learning and communication versus those who did not. Audio and video representations on video sharing websites and voice and video chat platforms on Skype have become popular with youth, but there has been little research on the effect they have on cognitive skill development. Video sharing websites (e.g. YouTube) may help children with out of school learning, particularly videos that feature how-to's; An and Seplocha (2010) have suggested that children can learn more intuitively by viewing dynamic visuals with the author's narration, as compared with modes that involve text-only instruction.

Hypertexts are interactive and allow users to access information in a nonlinear fashion at their own pace. This puts control in the hands of users and provides a dynamic reading context (Schmidt and Vandewater 2008). Research suggests that comprehension of hypertext is related to both general reading skills as well as navigation strategies specific to electronic reading contexts (Salmeron and Garcia 2011). According to Subrahmanyam and Greenfield (2008, 179), 'unlike books, in which pages are arranged in a linear fashion, the Internet allows much more complex forms of linking across several websites and pages within websites'. Navigating around a website may therefore require users to create mental maps of the site organisation, thus tapping into spatial visualisation skills. Corroborating this hypothesis, research with college students suggests that spatial visualisation ability predicts information-seeking success in electronic information contexts such as navigating hierarchical menu systems within databases and the Internet websites (Downing, Moore, and Brown 2005). Thus, it is possible that users with more Internet surfing experience may have better spatial visualisation skills (Subrahmanyam and Greenfield 2008).

Finally, as mentioned earlier, the Internet is not just restricted to a single continuous stream of information. It also allows for multiple applications at the same time and multiple windows within many applications. Thus, it facilitates and necessitates multitasking, especially in the realm of social communication, and creates a context in which young people multitask in ways that were not previously possible (Zevenbergen and Logan 2008). Extant research on multitasking has mostly been done on college students and the findings are inconclusive with regard to its cognitive effects (Carrier et al. 2009; Foerde, Knowlton, and Poldrack 2006; Tran and Subrahmanyam 2012). Research on young children's multitasking is needed to understand its consequences – including the potential benefits as well as costs.

2.3. *Content of computers and academic and cognitive skills*

In this section, we examine the third pathway of influence, which focuses on computer content and its effect on children's academic and cognitive skills. As noted earlier, computer content refers to the more specific goal-oriented educational content found in electronic games and online sites; such content is typically designed to enhance children's learning in areas such as language, reading and maths. Although there is a solid body of work on the effects of specialised educational software, most have focused on in-classroom use and compared them with traditional teacher-based instructional methods (for reviews of this work, see Glaubke 2007; Lieberman, Bates, and So 2009; McCarrick and Li 2007; Räsänen et al. 2009), and are not reviewed here. Research has not systematically investigated whether unstructured and informal uses of educational software can improve the academic and cognitive skills that are the focus of the software. The few studies that we found were done on specific groups such as low-income or dyslexic children, and we briefly examine them here.

In one study with low-income pre-school children (3–4 years of age), Huffstetter et al. (2010) examined the effects of an online educational website *Headsprout Early Reading* on the children's oral language and early reading skills. Although the study was conducted at a Head Start Centre, the intervention occurred in a mobile computer lab set up in a retrofitted school bus and the teachers' role was similar to that of a parent or another adult at home. The teachers escorted the children to the mobile lab, helped to familiarise the children with the set-up (e.g. adjusting volume on the head set) and provided support as needed (e.g. praised oral responding and praised episode completion). The online software was chosen for its ease of independent usage and required neither a reading vocabulary nor extensive training for teachers. The intervention involved daily use of the software for an 8-week period. The study used a pre-test and post-test control group design, and children in the control group used a computerised maths game (*Millie's Math House*). Children in both groups received the same in-class literacy instruction. The study results are encouraging, as the intervention group showed significant gains in reading skills (as measured by the Test of Early Reading Ability, 3rd ed. or TERA-3) and oral language skills (as measured by the Test of Language Development-Primary, 3rd ed. or TOLD-P: 3).

Along similar lines, Magnan and Ecalle (2006) conducted three experiments in France to examine the effectiveness of computer-based audio-visual skills training in a game-like context to enhance reading skills in dyslexic children with reading disabilities. Two of the three experiments compared computer-based training in the classroom routine with regular classroom-based instruction; these are not discussed here. The third experiment compared the effects of computer-based training administered at home by involved parents with at-school training administered by a neutral experimenter; the latter group did not use a computer at home and did not have regular access to a computer at school. The authors reported that the children showed greater gains in phonological skills from home computer training as compared with school-based training. The study's computer-based training used a game-like context and highlights the potential of educational software used informally within the home under the direction of a parent.

In another study of kindergarten children (mean age of 6.6 years) with low numeracy skill, Räsänen et al. (2009) examined the effects of playing two different researcher-developed computerised games, *Number Race* and *Graphogame-Math*. Although the study was conducted in a kindergarten setting, the actual intervention involved a 10–15-min session daily for 3 weeks, when children in the intervention group played either of the two games; a control group, matched in age and identified by teachers as not requiring additional support in early mathematical skills, did not participate in the game playing sessions. As compared with the control group, children in both intervention groups improved in number comparison but not in counting tasks. However, not all effects of computer content are positive. Hastings et al. (2009) found that playing violent computer games was associated with increased aggression and decreased school competence, grade point average and attention, whereas playing educational games had a positive association with attention and grade point average.

Based on the available evidence, we recommend use of computers for moderate amounts of time, 2–3 days a week for an hour or two per day and recommend that daily use not exceed 2 h per day. These recommendations are based on recent survey data regarding typical use among young children (e.g. Rideout et al. 2010) and will likely need to be revised as touch-screen devices become more common and children's overall screen time (television, computers, iPads, and so on) increases. We also recommend moderate playing of non-violent action-based computer games that use visual-spatial and attentional skills as well as complex problem solving. Potential gains from such use are specific to the particular skills used by the game and there may be limits to the cognitive gains from playing games. Based on the available evidence, we recommend the use of non-violent educational games designed to develop particular cognitive skills such as reading or numeracy. Use of such educational games is particularly appropriate for children at risk for reading or numeracy difficulties.

3. Children's computer use and the development of social skills

As compared with the literature on computers and cognitive skill development, research on the effects of the use of computers on the development of children's social skills is scarce. Drawing on our framework for understanding the cognitive effects of computers, we propose three pathways through which the use of computers may influence children's social skills: (1) time on the computer entails time spent on activities relevant to developing social skills and displaces time on activities (e.g. face-to-face interactions with family members) relevant to developing social skills; (2) opportunities for social engagement on the computer can help to develop children's social skills and (3) content of computers (e.g. software, games and websites) includes social themes (e.g. aggression, friendship and sharing), which may influence social skills. In the next sections, we present evidence to show that these three pathways of children's computer use – time, opportunities for social engagement and content – may have implications for their social skills (see Figure 2).

3.1. Time on the computer and social skills

To understand the relation between children's time on the computer and their social skill development, the first pathway considers the impact on both the individual child as well as the family system. Although there is a solid body of work on the effect of computer and Internet use on adolescents' well-being (see Subrahmanyam and Smahel 2011, chapter 7), we could not find comparable work with younger children. On the question of whether time on the computer displaces social activities, computer time generally seems to displace other solitary or minimally interactive activities such as watching television, listening to music and reading (Lanigan, Bold, and Chenoweth 2009). With regards to whether children's computer use displaces family interactions, Lee and Chae (2007) have reported that the total time using the Internet was related to perceived declines in family time, but not for family communication. Interestingly, parents' involvement with their child's use of computers by co-using was positively related to children's engagement in online educational activities (Lee and Chae 2007).

The study by Lanigan, Bold, and Chenoweth (2009) is also relevant to questions about the relationship between the use of computers and family relationships. Participants included visitors to 40 websites frequented by parents with children at home, post-parenting individuals and couples without children who were recruited through an online posting asking for volunteers. Forty-five percent of the participants viewed computers as having a positive influence on their family relationships, and only 21% viewed them as having a negative influence. Using the Family Adaptability and Cohesion Scale (FACES III), Lanigan, Bold, and Chenoweth (2009) categorised participants as belonging to four family types in terms of adaptability and cohesion: separated (9.3%), mid-range (33.7%), moderately balanced (44.2%) and balanced (12.8%). Separated families scored low on both cohesion and adaptability dimensions and were twice as likely to view the computer as having a negative impact on family relationships. Although the study did not present results in terms of the presence and age of children, nonetheless it suggests that the effects of computer use on social skills might be moderated by variables related to family functioning. In fact, research with adolescents and adults also suggests that many individual and personality factors moderate the influence of computer time use on social and psychological well-being (Subrahmanyam and Smahel 2011). Similarly, we expect that the effect of computer time use on children's family relationships might also be moderated by the kind of family activities that may be displaced, content of activities on the computer, family dynamics and individual characteristics (e.g. extroverted or introverted personality).

3.2. Opportunities for social engagement on the computer and social skills

A second pathway of computer influence on social skills is through the opportunities for social engagement that computers provide. Although computer-based activities tend to be viewed as solitary or individualised ones, they can actually provide many opportunities for social engagement through peer and family interaction, collaboration and even competition (McCarrick and Li 2007). Online communication tools such as email, social networking and instant messaging epitomise the social potential of computers. They are used primarily by older youth (Subrahmanyam and Smahel 2011) and are less popular among younger children (Rideout, Foehr, and Roberts 2010). Because this paper focuses on younger youth, we only examine the social implications of computer use that is not centred on the Internet and online communication tools.

Computers can provide many different opportunities for social engagement and interaction. For instance, they can serve as a catalyst for social interaction, such as when pre-school children need assistance with operating the computer and whenever they experience problems (Plowman and Stephen 2005). In fact, 3–5-year-old children in one study reported that they primarily turned to their parents for computer help (Stephen et al. 2008), whereas other family members (grandparents and siblings) were secondary. Interestingly, children did not identify their teachers or pre-school educators as sources of help with computers (Stephen et al. 2008).

Computers may also provide opportunities for users to co-operate, negotiate and collaborate, especially in informal settings where computer availability may be limited (Johnson 2010; McCarrick and Li 2007). In their review of several studies involving computer use in pre-school classrooms, McCarrick and Li found that the use of computers without adult support fostered social interactions among children, with more interactions occurring when children had to share computers (McCarrick and Li 2007). More computers in the classroom are more likely to reduce interactions in elementary school classrooms as compared with pre-school classrooms, where children have been found to collaborate with each other even when there were enough computers for everyone (Willoughby et al. 2009). The gender composition of the groups might also play a role in increasing or decreasing collaboration when using computers, but the evidence is unequivocal as to whether social interactions are enhanced by same-gendered pairings versus mixed-gender pairings (Willoughby et al. 2009).

Computer collaboration in informal group settings (e.g. the pre-school classroom) may also help children to develop socially and enhance their computing ability through negotiation of tasks with others. Research suggests that young children are able to engage in diverse social interactions when collaborating over their use of computers; they observe, teach, help, share, discuss and take turns (Glaubke 2007; Heft and Swaminathan 2002; Lieberman, Bates, and So 2009; Plowman and Stephen 2005). Glaubke (2007) has noted that children who used the computer for educational purposes used more complex speech patterns and exhibited greater language development, suggesting that interactive media can be used as a catalyst for social development.

As the computer is limited by its input devices – typically one screen, one keyboard and one mouse – it is often viewed as an individual activity; however, as discussed earlier, young children's computer use is often enveloped in social dialogues. Children have to negotiate the use of computers with adults, siblings and other children (at school), they have to seek assistance and enjoy using the computers with others. Although the social aspect of computer assistance decreases with growing competency (Plowman and Stephen 2005), social elements can be interjected into older children's use of computers by encouraging them to instruct younger children as well as less knowledgeable adults.

Playing computer games is another aspect of computer use that provides opportunities for social engagement. Research suggests that children are more likely to play games socially rather than solitarily; Hastings et al. (2009) found that among 6–10-year-old children, 44% played games alone, whereas 33% played with a sibling, 11% played with friends and 10% played with a parent. Although the research on this question is sparse, a review of early work concluded that playing computer games might have positive effects on social skills and relationships (Subrahmanyam et al. 2001). In a study of adolescents, Colwell, Grady, and Rhaiti (1995) found that when compared to less frequent computer game players, frequent players met friends outside school more often. In an early study of families with new home computer game systems, games brought family members together for shared play and interaction (Mitchell 1985).

Although we do not know the extent to which young children play online games (many online games have age restrictions), we do know that they visit virtual worlds (e.g. *Club Penguin* and *Whyville*), which are protected spaces that afford an online context wherein children can become immersed in a variety of activities while simultaneously socialising with other users (Subrahmanyam 2009). A key aspect of virtual worlds is that users name and create online avatars, which are their representations within that space (Subrahmanyam 2009). The act of creating an online avatar and identity, and using that online representation to interact with peers within a social setting may have implications for children's identity and social skill development. More research is needed to understand the potential benefits as well as costs of such virtual social engagement.

3.3. Content of computers and social skills

Finally, we consider the third pathway, which considers the effect of computer content (e.g. software and games) on children's social skills. Because of the similarity in the interactive gaming experience across different hardware platforms (e.g. video game systems/consoles, computer games and online games), we draw broadly from the video game literature (Anderson et al. 2010; Sestir and Bartholow 2010) and expect content effects from playing computer games to be similar to those obtained from playing video games. Our focus is on content related to social skills and relationships, such as aggression, as well as more pro-social themes, such as friendship and sharing. The research on the playing of violent video games is quite robust and has demonstrated effects, such as increased aggressive behaviour (Sestir and Bartholow 2010), cognition, affect and decreased empathy (Anderson et al. 2010). In fact, a meta-analysis by Anderson et al. (2010) found only weak evidence for cultural differences (across Eastern and Western countries) and found no evidence for sex or age differences in susceptibility to the effects of violent video games. For a review of the theoretical explanations regarding the effects of playing violent games on aggression, see Whitaker and Bushman (2009) and Anderson et al. (2010).

In contrast, playing non-violent video games appears to have more positive effects. Sestir and Bartholow (2010) demonstrated that non-violent video games do not have to be explicitly pro-social to have pro-social effects. They used a cognitive word completion task in which participants filled in blanks to complete ambiguous words, and a story completion task in which participants were asked to complete 15 items detailing the ending of an ambiguous story involving a potentially stressful incident (Sestir and Bartholow 2010). Participants who played a non-violent game had decreased aggressive thoughts and feelings compared with those who played a violent video game on both measures and compared with participants in the no game control for the story completion measure. Similarly, a review of four studies revealed a link between pro-social gaming and pro-social behaviours across Singaporean students, Japanese children and adolescents and US undergraduates (Gentile et al. 2009). In sum, research from video games suggests that both aggressive and pro-social messages in electronic games can influence children's aggressive and pro-social behaviours.

Based on the available evidence, we recommend that children's use of computers should be monitored so that it does not displace social activities such as interactions with peers and family members. Children should also be encouraged to use computers in ways that provide opportunities for social interaction and collaboration such as (1) children co-using the computer with their parents, siblings and peers, (2) setting up computers in ways that foster social interaction, such as placing computers in shared spaces, having children share computers with siblings and having fewer computers than children in informal group settings (e.g. after school programmes and summer camps) and (3) children playing computer games with others (peers, parents, relatives, and so on) as a social activity. We also recommend that children access computer games and monitored online content that contain pro-social and non-violent themes and avoid content that contains aggressive and violent themes.

4. Discussion and conclusion

Children are growing up with computers as an important part of their lives, and it is important to consider the implications of their computer use. Surveys suggest that outside of school, children use computers to play games, watch videos, surf the web and visit virtual worlds. To present the evidence on the effects of children's informal computer use, we proposed three potential pathways by which the use of computers could influence their academic, cognitive and social skills. The pathways for academic and cognitive skills include time on computers as well as the formal features and content of computers; for social skills, they include time on computers, opportunities for social engagement and the social themes of computer content. Based on the evidence presented, we proposed guidelines for the informal use of computers by children to promote the development of their academic, cognitive and social skills (see Table 1).

In this section, we critically analyse extant research on the effects of computer use on children's development and identify questions and issues that must be addressed in future research. With regards to the pathway of time, research has mostly measured overall computer time through self-reports or parental reports when the participants were young children. Such self-reports are susceptible to distortions and memory lapses, and typically do not take into account what children do with that time (Subrahmanyam and Smahel 2011). Multitasking and hand-held portable devices are adding to the challenge of measuring screen time. To better understand how computer time use impacts academic, cognitive and social skills, future research must use more accurate methods to measure computer time such as automatic activity software and should also take into account what children do with that time.

With regards to the formal features of computers, research to date has shown that informal use of computers, particularly games, can have positive cognitive effects on visual-spatial skills, attention and processing speed. However, many questions remain unanswered about these findings. For instance, all of the studies have only used short-term training, typically a few hours of training spread out over a few days, and tested for gains immediately after. We do not know whether the effects are long lasting and whether gains plateau out after initial increases. In fact, some of the studies have found the most gains among children with less experience playing games or children who had lower scores to begin with, suggesting the possibility of ceiling effects (e.g. Subrahmanyam and Greenfield 1994). Finally, we do not know whether the effects of short-term computer-based training transfer to non-computerised contexts. Future research must also systematically isolate the cognitive effects of other formal features of computers and the Internet such as audio and text-based representations, interactivity, hypertext and multitasking.

The third pathway of influence focuses on informal use of computer content. Although research on content effects is sparse, their findings suggest that in-home use of specialised educational software may help at-risk children. Well-controlled studies are needed to investigate whether such effects generalise to typically developing children, and to identify sub-groups (e.g. low-income and/or language minority groups) that might benefit the most from such use. Research must also identify the particular kinds of use (daily, weekly, and so on) and features (dynamic and interactive) of educational software and computer content (e.g. websites) that are most effective, as well as whether benefits are persistent and transfer from informal contexts to formal settings such as the classroom.

Although children's use of computers seems to mostly displace solitary activities, and computer time is perceived as having a positive influence on family relationships, future work must examine whether effects are indeed positive and must also identify family variables such as family functioning that might moderate the effects of computer time use. Whereas research points to the potential for computers to provide children with opportunities for social engagement, studies must examine the particular conditions (e.g. collaborative vs. competitive play) when use is most likely to lead to gains in social skills. Similarly, a solid body of video game research has shown that violent and pro-social content in games and software influences children's social behaviour such as aggression and helping/sharing. We do not know at this time whether similar effects occur from producing, consuming and engaging with such content in online contexts (e.g. websites and video sharing sites such as YouTube).

Finally, although our framework highlights each pathway of computer use influence, they likely influence cognitive and social skills simultaneously. A challenge for future research is to examine how the different aspects of computer use interact with each other and with child characteristics (e.g. age, gender and skill levels) to influence development.

The role of gender in moderating the effects of computer use is not well documented, even though there are consistent gender differences in children's use of computers and other interactive media. Boys are more likely to have access to a home computer, use the computer more frequently, spend more time on average on the computer and spend more time playing games (Rideout, Foehr, and Roberts 2010; Vekiri and Chronaki 2008). There are also differences in the genre of the games played; boys prefer fantasy/violence, sports and action adventure games, whereas girls prefer educational, action adventure and entertainment games (Cherney and London 2006; Subrahmanyam and Greenfield 2011; Hastings et al. 2009). Such differences in game genre preference may have long-term implications for children's development, given that effects of playing games (e.g. gains in spatial skills and attention) are tied to specific game genres (e.g. action video games) (Dye, Green, and Bavelier 2009a; Subrahmanyam and Greenfield 2008). With regards to game characters, main as well as ancillary characters tend to be male (Kirsh 2009; Subrahmanyam and Greenfield 1998), and both male and female characters tend to be gender stereotyped (Sheldon 2004). Because children may be more attentive and engaged when they can identify with game characters (Subrahmanyam and Greenfield 1998), research must also examine whether gender discrepancies in game characters moderate the effects of computer use.

In conclusion, we have shown that different aspects of informal computer use can influence children's academic, cognitive and social skills in different ways. As computers and other interactive technologies get smaller and more mobile and as they become more firmly entrenched in young people's lives, we expect that they will influence development in even more diverse ways than we have described. Future research should systematically examine when the effects stemming from the use of computers are most likely to occur so that we can better harness their potential as well as protect children from any harm.

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