

The 4Cs for Young Children's Technology: Create, Connect, Communicate, and Control

The 4C's for Children's Technology

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ABSTRACT

The phenomena surrounding computers has, during the past 10-15 years, broadened to become a non-trivial component of young children's lives. This broadening is happening at a time when many technologies include dark patterns that induce compulsive use, disregard privacy, and lead to passive, isolating experiences. As a counter to these developments, we build on the 3Cs approach to young children's technologies (create, connect, and communicate), and propose a 4th C: control. We call for technologies that give children and caregivers control over their activities, time, data, and decision-making. In this paper, we provide a historical and child development perspective to motivate our approach, present its characteristics, illustrate it with examples, and discuss challenges and opportunities.

CCS CONCEPTS

•Human-centered computing~Human computer interaction (HCI) •Social and professional topics~User characteristics~Age~Children

KEYWORDS

Young children, preschool children, create, communicate, connect, control, dark patterns.

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1 Introduction

Computer science became a field independent from its parent disciplines, mathematics and electrical engineering, in the 1960s. In defending the field as its own area of study, future Turing Award winners, Newell, Perlis, and Simon, defined computer science as "the study of the phenomena surrounding computers" [33]. Around the same time, Louis Fein, who coined the term *computer science* [11], expressed

his views on why society should invest in computing saying "What the hell are we making these machines for, if not to free people?" [54]. Moving forward 60 years, the phenomena surrounding computers has expanded tremendously, with a recent addition being widespread use of computers by young children [38]. It is unclear though, whether this expansion has had an overall benefit on young children and society given the passive characteristic of prevalent uses of technology by young children [38] and serious concerns about privacy [36] and compulsive use [12,13].

About 6 years ago, a group of child-computer interaction researchers proposed a novel approach to technologies for young children that contrasted with prevailing approaches. They argued for more technologies for this age group to support creativity, communication, and a connection with the social and physical environment around children (3Cs) [24]. In this paper, we second their call and add a fourth C to address challenges related to privacy and compulsive use of technologies: control. Our contributions include a contextual and interdisciplinary motivation for the 4Cs approach, guidelines for technologies to follow the 4Cs approach, a clear description of how it can be brought to practice including examples of existing technologies, and a discussion of opportunities and challenges ahead.

In the following sections we first provide a historical context for the latest changes in computing to establish how they differ from historical trends and discuss child development and how it could be affected by dark patterns in computing. We follow this discussion with a summary of the 3Cs approach, describe the 4th C (control) and how it can be applied to technologies, provide examples of 4C technologies already in use, and discuss more broadly implications for child-computer interaction.

2 Historical Context of Human Factors Developments in Computing

Various times have been proposed as the beginning of the human-computer interaction (HCI) field, whether related to the first CHI conference in 1982 [43], the beginning of the Software Psychology Society in 1976 [43], Engelbart's

“Mother of All Demos” in 1968 [10], or Sutherland’s work on Sketch Pad in the early 1960s [48]. These events tend to be related to personal computing and the evolution of graphical user interfaces. We argue that more broadly, human factors have been involved in many major changes in computing, from the inception of digital computing to this day. Below, we provide a few examples with the goal of illustrating how these changes have broadened uses of computing by more people, even at the cost of higher execution times, and expanded the applications of computing. We present these changes to illuminate the difference between the latest developments in computing and prior ones in terms of user control.

One of the first obvious examples was the switch from implementing algorithms through hardware to implementing them primarily through software. The ENIAC, the first electronic computer to run in the United States (and the only one for five years), initially had to be programmed through rewiring [45]. This literally involved running wires between electronic components. It was not until 1948 when the first bit of software was written and implemented, based in part on ideas laid out by John von Neumann in 1945 [27]. This change gave computer users more control, by adding flexibility, lowering cost, and saving time, which made slower execution times worth it, while keeping the option to implement algorithms through hardware when it made sense.

About ten years later, another change was from programming primarily through assembly language to using human-like high-level programming languages. The first meeting to discuss these emerging languages happened in 1956 [41]. Again, programming in these languages did not yield more efficient code than writing in assembly language, but it significantly expanded both who could program computers and their application areas, giving control over computers to more people.

Moving to the 1960s, another major change in computing was the broad adoption of operating systems, such as IBM’s OS/360, which went beyond batch-processing systems that started in the 1950s to enable programming once for a wide variety of hardware configurations, as opposed to programming the hardware directly [16]. Adding this extra layer of software again gave users more control over computers by having specific configurations not impact human processes even at the potential cost of longer execution times.

Perhaps one of the changes that HCI researchers and professionals are most familiar with is the one from the use of command-line user interfaces to graphical user interfaces (GUIs) for non-technical users. This change started with the ideas from Sutherland [48] and Engelbart [10] mentioned above, continued with developments at Xerox PARC during the 1970s [26,29], and broadly used operating systems starting in the 1980s and taking hold during the 1990s. Again, expert users can typically be more efficient using the command-line than a GUI, but GUIs broadened access to more

users. The World Wide Web [5] borrowed many of the nascent ideas from HCI and GUIs for a simple, consistent, and flexible user interface that appealed to an even broader set of users. GUIs in particular not only gave more users control over computers, but also significantly lowered the time that had to be dedicated to learn how to use computers.

In the late 2000s, the release of Apple’s iPhone [37] provided the first highly usable mobile touchscreen user interface, so usable that even frogs [53] and bearded dragons [25] can make intentional use of them. This unprecedented broadening of access also included, for the first time, young children [23], who prior to these devices being available faced barriers to using a mouse and keyboard [22].

The latest changes in computing are related to the ubiquity of computing provided by mobile computing, high-speed Internet access, and smart devices, combined with the massive ability to capture, store, and process data. These changes are again further broadening the impact of computing and where it is available. Consider how computers are affecting our cognitive processes, such as how we perceive the world, what we need to remember, what we pay attention to, how we learn, and how we make decisions. Newell, Perlis, and Simon’s “phenomena surrounding computers” [33] has become incredibly broad.

There is something different about this latest set of changes though. They have come at an unprecedented cost in terms of control due to prevailing business models [32]. Control over our privacy, our information, and our relationship with computers. Is our current relationship with computing setting us free, per Fein’s promise [54]?

3 Relationship Between Young Children’s Development and Computing

Child development is a dramatic process, in particular during the first few years of life. Changes in reaction time [28] (the inverse of information processing speed) provide a sense of the pace of development (see Figure 1).

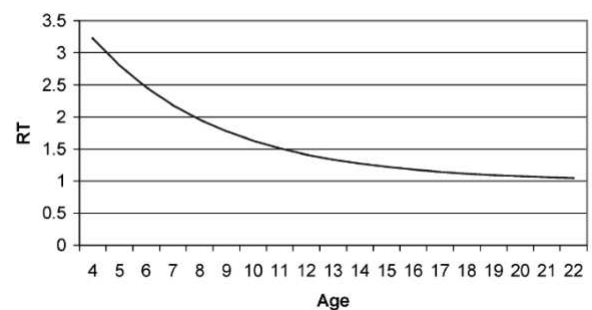


Figure 1. Reaction time by age in years [28].

While there has long been controversy on the nature versus nurture debate, more recent views on development point at both genetics and the environment interacting with each other over time to affect development [18]. Gottlieb’s

perspective, shown in Figure 2, illustrates bidirectional influences from genetic to neural activity, to behavior, to the environment, and back [18]. It is easy to understand the top layer: our behavior can change the environment and the environment can change our behavior. But behavior is driven by neural activity, and neural activity is affected by the outcomes of our behavior. Likewise, gene expression impacts neural activity, and there is evidence that neural activity can in turn affect gene expression [18]. Note that gene expression is not the same as DNA, it refers mainly to using information from a gene to produce RNA molecules and proteins [7]. Gottlieb's views fall within a systems perspective of development that has been increasingly embraced by developmental psychologists since the 1990s [8,14,19,39,40,50].

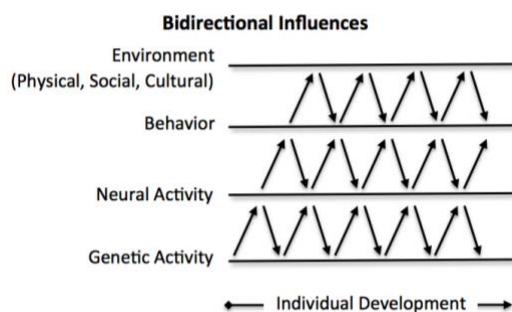


Figure 2. Bidirectional influences between the environment and genetic activity [18].

How are Gottlieb's views relevant to the relationship between young children's development and computing? Computers are increasingly mediating children's interactions with the environment. As more of children's time is spent using computers, this use, according to Gottlieb's bidirectional influences, should have an impact on their behavior, neural activity, and gene expression. These effects are likely to have a greater impact on young children, whose neural structures are changing so quickly [28]. In other words, the concern is about how digital media can impact young children's cognitive development [1].

The concern is due to the steady increase in young children's use of mobile devices. In the United States, for example, a survey conducted right before the COVID-19 pandemic found that about half of 2-4-year-old children and two-thirds of 5-8-year-old own a mobile device [38]. The same survey found an average use of about one hour a day for 2-4-year-old children, with the most common uses being watching videos (37 minutes a day) and playing video games (10 minutes a day) [38]. Only 28 percent of 2-4-year-old children accessed media with a parent most of the time [38]. Lower-income children 8 years old and under were more likely to spend more time on mobile devices, more than three times as much as their high-income peers [38]. In other words, use of these devices by young children mostly involves passive

consumption of media, which does not necessarily involve creativity, communicating with others, or connecting with the surrounding physical space. The impact of these experiences on children will largely depend on the quality of the media they access (e.g., is it educational or for entertainment purposes), the amount of time spent on it, and the social context in which it is used (e.g., with parents or individually) [1].

4 Dark Patterns in Young Children's Technology

Part of what is likely behind the rise in use of mobile devices by young children is the business model behind most of the apps, which involves providing a free app in exchange for personal information [32]. Children's apps are no exception with a recent study finding that 67 percent of the top 1,000 children's apps for Android and iOS transmit location, with close to half including location and IP address in the ad bid stream, and about 40 percent having potential access to personal information, such as photo or video files [36].

The additional challenge is that this business model also incentivizes app designs that lengthen use, such that apps can deliver more advertisements and gather more data. In other words, this business model leads to addictive designs [32]. Dark patterns related to incentives for compulsive use have previously been identified as widespread in popular children's mobile games [12,13].

Going back once again to Fein's promise [54], can we say that these uses of computers are setting children free?

5 Proposing the 4Cs for Young Children's Computing

While it is easy to criticize the current context of young children's interactions with computers, it is more difficult but necessary to use creative imagination to invent better futures [17]. Our proposal is to use an existing approach proposed a few years ago, the 3Cs [24], and add one more component to bring it up to date with what we know about young children's current interactions with computing.

5.1 The 3Cs: Create, Connect, and Communicate

The 3Cs approach to preschool children's use of technologies proposed to make more of children's activities with technologies support creativity, a connection with the social and physical environment around children, and face-to-face communication with other children and caretakers [24]. The inspiration behind the activities to be supported came from Vygotsky's sociocultural approach to child development and some of its successors [6,51]. It was also inspired by Papert's perspectives on learning [35]. Both elevate social, creative activities, with Vygotsky in particular putting an emphasis on the role of language and tools [6,51].

The key characteristics of activities proposed in the 3Cs approach and how they contrast with non-3Cs activities are summarized in Table 1 [24]. It is clear from the concepts on the table that the 3Cs approach attempts to address many of the concerns with the current use of technologies by young children [24]. There is a clear emphasis on social aspects and the use of technology to facilitate beneficial activities as opposed to being the focus of activities.

One observation is that the 3Cs approach resembles in many ways more traditional child play activities that do not involve technology. The question then is, why bother using technology at all? The 3Cs authors answered with five areas where computer technologies could add value: bridging abstract and concrete thinking, linking children to their strong interests, enabling a wider range of entities to be created and shared, providing additional channels of communication, and scaffolding beneficial activities [24].

Note that the authors of the 3Cs approach did not necessarily call for all young children's technologies to follow the approach, but rather for a proper balance between the use of 3Cs and non 3Cs technologies [24].

Non 3Cs Approach	3Cs Approach
Social isolation	Communicate with adults & peers
Primary focus on device	Connect with social & physical environment
Experience media	Participate in creative activity inspired by media
Same experience for everyone	Tech facilitates adults & children planning their own activities
Instant gratification	Delayed gratification
Use interests to maintain engagement	Immerse children in their interests to arrive at powerful ideas

Table 1. Non 3Cs versus 3Cs activity characteristics [24].

5.2 Adding a Fourth C: Control

While the 3Cs approach has many components that address current concerns with young children's use of technology, it does not fully address the concerns we previously outlined under section 4. What is missing is addressing dark patterns that involve privacy risks and that promote compulsive use of technologies. Both these dark patterns remove control from children and their caregivers over their data, their time, and their behavior.

Hence, we propose a fourth C to be added to the 3Cs: control. A focus on control is not new in human-computer interaction. One of Ben Shneiderman's golden rules is to "support internal locus of control" [44]. He argued that users should feel in control, should initiate actions, and the system should behave as expected. This golden rule was inspired by experiences with software with poor usability in the early

years of the human-computer interaction field. Our sense of control goes beyond Shneiderman's to call for technologies that respect privacy and that do not attempt to manipulate behavior for profit.

Table 2 outlines the characteristics of 4Cs technologies that add on to those of 3Cs technologies presented in Table 1. The characteristics we propose go beyond technology itself to the activity surrounding the use of technology. This is consistent with the view within child-computer interaction to "design the ecology, not just the technology" [21].

The first characteristic we propose is to move away from designing technologies such that they are a required component of activities and instead use technologies as a scaffold [42] to facilitate beneficial activities. The idea is to have more technologies designed such that they are not necessary in the long term. Rather, they help children gain skills or knowledge to participate in beneficial activities and no longer need to be used once children have achieved these goals. Another way of thinking about it is that instead of measuring a technology's success based on how long it is used, its success is dependent on children achieving developmental objectives. In terms of control, this characteristic removes dependence on technology, at least in the long term, returning control to children and caregivers.

The second characteristic we propose is to design activities that involve intentional disengagement from technology, as opposed to design for compulsive engagement. This concept builds on the 3Cs characteristic of activities inspired by media. The idea is for there to be just enough technology to facilitate beneficial activities (e.g., help plan or inspire them, provide support) and that these activities involve a focus on other children, adults, and non-electronic objects. The technology itself may prompt or provide incentives to move to activities where technology is not present or moves to the periphery, similar to Hiniker's approach to motivate non-use of distracting technology [20]. Success is based on the ability to inspire and support beneficial activities, rather than how much time is spent on the technology. It involves children and their caregivers having control over their time.

Privacy is the focus of the third characteristic. Under a 4Cs approach, the only form of data collection acceptable is not connected to individual users (i.e., it is not personally identifiable), is freely consented to, and is an integral part of the activity and/or used solely for the purpose of improving the technology. Such uses could include understanding which portions of the technology are being used, patterns of use, or information necessary for the system to function. Access to location, IP address, microphone, or camera use that is transmitted and processed remotely would therefore not be part of a 4Cs technology (there could be exceptions if the data does not reveal identities). This is in contrast to technologies that are designed for the purpose of collecting data, sometimes for delivering targeted advertising, other times to

just sell the data [36]. It is also in contrast to technologies that collect sensitive data, even if it is not for profit purposes, that could one day be exposed by malicious actors [9]. This characteristic of a 4Cs technology gives children and adults control over information about them.

Lack of Control	Control
Activity not possible without tech	Tech as a scaffold to activity
Compulsive engagement with tech	Intentional disengagement from tech
Personal data collection as part of business model	Privacy-preserving data collection used to improve technology/make it function
Tech in control of activity	Adults and children in control of activity

Table 2. Characteristics of technologies that lack or include the 4th C (control).

The final characteristic goes back to Shneiderman's "internal locus of control" [44]. This aspect of the 4Cs is about who gets to control what happens in activities involving technologies. It is about giving meaningful choices to children and their caregivers rather than imposing ways of using a technology. It puts technology in a support role, providing users with options, and keeping them in full control. Others have explored the spectrum of full autonomy for technology to user control in the realm of robotics [3]. In the same space, Elbeledy et al. noted how little work in Human-Robot Interaction envisions teleoperated robots (fully under human control) as opposed to fully automated robots. The full human control in this 4Cs characteristic gives children and their caretakers control over decision-making.

6 Examples of 4Cs Technologies

Examples of 4Cs technologies have a common thread in supporting social, flexible, creative, and physical activities. These activities often resemble activities without technology, but technology inspires, adds interest, or enables better support.

6.1 StoryCarnival: Set Up Make-Believe Play

The 3Cs paper described the early development of a system called StoryCarnival which included 1) interactive stories intended to serve as inspiration for roleplay with generic props (e.g., blocks) and 2) a character selection tool to support children in planning their play [24]. Five years later, StoryCarnival is publicly available at storycarnival.org. The stories are available as either e-books or printable PDFs, allowing for intentional disengagement from screen-based technology when appropriate. There are also story templates that allow children an extra degree of control over the content

of the stories, providing options to select from for settings, characters, and objects or events in the stories. StoryCarnival uses technology to set up and support social play, but the main activity supported by the system consists of children engaging with each other and with the non-electronic physical space and objects around them.

StoryCarnival now includes an adult-operated voice agent to provided parents, teachers, or other caregivers an alternate channel of communication with children during play [34]. The voice agent is a Bluetooth speaker decorated to look like a character which uses text-to-speech synthesis to "speak" to children during play as directed by an adult. An early version of the voice agent included a tablet app children could use to control the agent's speech during play, but Pantoja et al. found this led children to focus on the tablet screen rather than their peers or other play activities [34]. Relying on trusted adults to operate the voice agent and mediate children's interactions with it prevents reliance on the technology to record and process children's speech without compromising the other 3Cs.

6.2 Head Up Games: Augmenting Traditional Social Games

Head Up games are designed in opposition to location-tracking augmented reality games like Pokémon Go in that they do not focus children's attention and interactions on screen-based interfaces [47]. Instead, handheld devices are used to add interactions or mechanics to traditional children's games which could include running or other activities that require focus on children's surroundings. The handheld devices sense proximity to other handheld devices which can enable, for example, a game of tag to include an invisible indication that someone has been tagged via vibration [2]. Soute et al. described a challenge in maintaining children's interest in Head Up games over time and suggested support for leveling the games could sustain children's interest [47]. Because children often improvise, negotiate, and iterate on game rules, Avontuur et al. explored using a simple GUI to allow children to set parameters to change the rules of a Head Up game (e.g., the number of teams, the number of home bases, etc.) [2]. They found children were able and motivated to adjust game rules using the interface and the presence of an adult facilitator (a camp counselor) helped to manage conflicts when children disagreed on the rules they wanted to play by [2].

6.3 Augmenting Traditional Playgrounds

Other work embeds technology and infrastructure within a specific environment, such as a playground, again making it unnecessary to track specific children's location. Lund et al. developed tangible tiles which could be used as building blocks to create interactive floors and walls and programmed to support different games (e.g., to turn all the tiles a specific color by pressing them) [30]. The Interactive Slide project

used an infrared camera to track children's interactions with images projected on an inflatable slide without requiring full images of the children [46]. Tetteroo et al. described the concept of interactive playgrounds as game spaces which would ideally partially contain play [49]. In other words, play on an interactive playground should ideally make use of elements of the technology and infrastructure but also contain elements that do not rely on that specific environment (e.g., a make-believe pretense). That goal opens possibilities for a single play session on an interactive playground to inspire different-but-related play on traditional playgrounds, at home, or in other contexts.

6.4 Social Play Things to Support Open-Ended Play

Interactive play objects which respond to simple interactions (e.g., a cylinder which changes color when rolled) can support children in open-ended play and inspire them to create their own games [4]. Frauenberger et al. designed three sets of interactive play objects they call Social Play Things with groups of neurodiverse children [15]. LightSpaces were magnetic pieces of fabric which lit up different colors when children squeezed primary color inputs (e.g., if one child was squeezing blue while another was squeezing yellow, the lights would turn green). The pieces of fabric could be attached to furniture or other objects. MusicPads were tiles which made sounds when pressed and could be used to create dancing games or puzzle games in which children tried to systematically figure out what each tile does. PictureStage was a lamp which could project children's drawings and recognized specific tagged cubes which prompted it to apply different effects to the projected image (e.g., inverting the colors). With each of these prototypes, children negotiated control of the technology and surrounding play activities within their groups. Critically, Frauenberger et al. described the importance of incorporating layers of technology such that play objects can function either with or without the technology layer [15]. For example, the magnetic fabric could be used in costumes or set designs without the lights and the tiles could be used as steppingstones without producing any sound. This principle applies to work in other areas as well: the Interactive Slide, for example, could still function as a slide without any augmentation [46].

6.5 Osmo: Tangibles in a Spectrum Toward 4Cs

Osmo [55] is a commercial product that is in the spectrum between non-4Cs and 4Cs technologies. With Osmo, young children use an app on a tablet that uses a camera to see how children manipulate non-electronic tangible items. These tangible items can be used, for example, to form letters to help children learn the alphabet [31], or play board games to learn mathematics [52]. The apps direct the activity and children interact with them by manipulating tangible items in front of the tablet.

How does Osmo do with respect to the 4Cs? While Osmo is mostly intended to be used individually by children, it can more easily afford collaboration than typical tablet apps. Children's focus is split between the tablet and tangibles. While media drives the experience, there is room for creativity, and the activities are educational. In terms of control, the app is a bit further from the 4Cs since many of the activities are not possible without the tablet, and the apps drive the activity. However, there is no design for compulsive engagement and the company's business model is based on the sale of its products rather than data collection.

7 Discussion

The examples in section 6 illustrate a broad range of ways in which 4Cs technologies can be implemented, making it clear that the concept is not utopian, but possible. Also of note is that, as demonstrated by Osmo, there is a spectrum between 4Cs and non 4Cs technologies. What we argue for in this paper is not that young children only use 4Cs technologies, but that there be a balance in the technologies they use, and that the most harmful dark patterns discussed in section 4 be avoided altogether. For example, we think it is quite reasonable for young children to watch educational media or play educational apps from reputable sources. At the same time, we propose that these activities can be balanced with others closer to the 4Cs.

There are many opportunities for more 4Cs technologies. Part of the pattern with the technologies in section 6 is that they ease, inspire, or support existing non-electronic, beneficial activities. One area of inspiration for future 4Cs technologies may therefore be similar activities for children that could also benefit from extensions. The challenge is how to make these technologies more broadly available, which may involve some level of flexibility in deployment and business models that are like Osmo's or the support of non-profits or government agencies.

The 4Cs can also be a useful lens through which to think about how new developments in computing could benefit children and how to spot potentially harmful implementations. A timely example is generative artificial intelligence. Systems that could develop novel narratives to inspire beneficial activities for children could be tempting to use with young children. The 4Cs would emphasize that such technology be controlled by caregivers, who may partner with such a system to ensure the quality and appropriateness of such narratives. A 4Cs approach would also curtail data collection that is often part of these systems. On the other hand, a non-4Cs use of generative artificial intelligence could deliver a never-ending stream of unknown quality media for kids that exacerbates current problems.

The 4Cs view on privacy can also inform the relationship between data as a commodity, academic research, and industry. Increasingly, a non-trivial portion of academic research in computing relies on massive data collection

typically by third parties, which could include commercial toys or kits for young children. With a 4Cs approach, any such data collection would have to occur with parental consent and control over their data, with a preference for gathering as little data as possible to evaluate the technology, improve it, or make it function.

8 Conclusion

It is time to use our creative imagination to rethink technologies for young children. Current trends involve too many dark patterns leading to isolation, passive consumption, disconnection from physical spaces, compulsive use, and threats to privacy. The 4Cs provide a guide to a different approach. In this paper, we have motivated the 4Cs approach, described it, provided examples of actual technologies compatible with it, and discussed future threats and opportunities. Throughout most of the history of computing, the changes that broadened use and access preserved user control. It is time to get it back and ensure it is there for young children too.

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