CHAPTER 12

Understanding the Technical and Social Complexity of the Internet: A Cognitive Developmental Resource Perspective

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The Internet is a special artifact system that is rapidly changing and complex, both technically and socially. The Internet has enormous technical complexity given its gargantuan nature as a special system that connects millions of networks and computers and billions of users worldwide. This complexity is almost invisible to the human eye but includes multilayer communication protocols (e.g., TCP/IP and MSTP), many physical connection devices (e.g., cables and satellites), and an abundance of application programs for users (e.g., email and web browsing). The vast number of networks is the primary technological feature of the Internet (Ralson, Reilly, & Hemmendinger, 2000). The Internet also is characterized by social complexity, given the multiple positive and negative effects of the Internet on an individual's life, such as facilitating communication across the globe while potentially breaching one's security and privacy.

Not surprisingly, children may find it challenging to understand the Internet through direct experience given these multiple facets of complexity. One reason for this difficulty may reflect the relative newness of the Internet and that it remains an emerging concept. There is a lack of formal education to teach children about the Internet and limited social scaffolding provided by adults, who may have inadequate understanding of the Internet themselves. Another reason is that the Internet is virtual. As an entire virtual world, it is not immediately accessible for children to experience through their senses (e.g., children cannot use their eyes to directly see the entire virtual space or use their hands to hold the gigantic virtual world), making

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it challenging for children to imagine its complexity. Further, the Internet is highly connective and extremely open to everyone. Therefore, by design, the Internet is essentially free from control by an authority so that, in principle, any individual throughout the world can post materials online at any time at a high speed and low cost—another unique feature hard for children to imagine. Collectively, these qualities make it difficult for children to understand accurately the complexity of the Internet through their direct, hands-on experiences.

Similarly, there are perceptual and conceptual challenges faced by children when interacting with the Internet that compromise their ability to understand its complexity. To understand a concept, we generally rely on both perceptual processes and conceptual processes. Our perceptual processes rely on sensory-motor experiences to support us to understand a concept; our conceptual processes rely on abstract reasoning to go beyond the direct sensory-motor experiences (Dewart & Brace, 2006; Eysenck & Keane, 2000; Margolis & Laurence, 1999). When interacting with the Internet, perceptual knowledge is formed through direct experience with the computer screen, mouse, and keyboard. Typically, the external and internal features of an artifact are quite similar, such as with balls or books whereby their surface features (e.g., a round shape or a book cover) match their internal functions (e.g., bouncing up and down of the ball with a force or specific contents of the book to read) so that individuals can recognize a ball by its shape or know a book by its cover. Thus, children can develop considerable knowledge about artifacts through their sensory-motor direct experiences with them. However, the Internet is perceptually misleading, as a complex and virtual universe that is practically invisible to the user who only interacts with its simple interface on a computer screen. Additionally, the Internet does not have a fixed or distinctive interface. Instead, a computer screen becomes a single node of the Internet only when the Internet is accessed and it seamlessly switches back to a computer once the Internet is turned off. Consequently, as a perceptually misleading artifact, the Internet is a challenging concept for children to understand.

Conceptual knowledge, by comparison, develops later as the user interacts with various aspects of the Internet, including visiting websites or sending emails or instant messages. One conceptual challenge in understanding the Internet is its profound social and technical complexity. A second conceptual challenge is that the Internet is an artifact that is different from other physical, social, or psychological entities (Keil, 1989). Children's rich domain-specific knowledge about various concepts, such as those in biology (e.g., alive or dead) or physics (e.g., matter or speed) may not be a useful intellectual resource for understanding the Internet. This situation may result in ontological confusion for children when attempting to integrate their domain-specific knowledge in biology or physics with knowledge about the Internet (Wellman & Gelman, 1998). A third conceptual challenge is that the Internet is a virtual artifact that is not physically accessible in the real world. Other artifacts that children encounter on a daily basis, such as television, telephones, and computers, are physically accessible and allow the child to directly interact with them in the real world (e.g., Cameron & Lee, 1997; Huston & Wright, 1998; Marsh, 2006; Scaife & van Duuren, 1995). As a virtual artifact, the Internet can only be accessed indirectly, which makes it challenging to develop an accurate conceptual understanding of it, not only for young children but also for ordinary adults.

EARLY RESEARCH ON HOW INDIVIDUALS UNDERSTAND THE INTERNET

At present, there is very little research on developmental differences pertaining to children's understanding of the Internet as compared to the well-studied concept of television (e.g., Anderson et al., 2001; Calvert & Kotler, 2003; Huesmann, Moise-Titus, Podolski, & Eron, 2003; Huston & Wright, 1998; Singer & Singer, 2001). Denham (1993) conducted one of the few studies that examined children's understanding of computers. In this well-cited study, 9- to 14-years-old children were asked to draw pictures of the inner workings of a computer in a series of three studies. The top five inner workings that children drew were a communication link, a computer chip, input and output features, memory, and transport (Denham, 1993). Older children were more likely than younger children to include more or all of these top five components. Ostensibly, older children were more likely to view a computer as multifaceted than younger children.

One of the earliest efforts to examine how children understood the Internet was conducted by Luckin, Rimmer, and Lloyd (2001). These researchers investigated differences between children's understanding of the Internet before and after their school gained Internet access during the school year 1998–99. Prior to the school going online, none of the 9-year-old children in the study viewed the Internet as having complex connectivity. After going online, only 10% of these children viewed the Internet as complex, despite having gained more online experience at school. Similarly, the percentage of children who considered the Internet as having simple connectivity just between two computers decreased slightly from 35% to 28% during the school year. Further, whereas 66% of the children in the study initially saw the Internet as merely a computer, 62% presumed as such after the school went online. These findings suggested that young children's increased Internet experience only slightly increased their understanding of its complexity.

Few studies have investigated adults' understanding of the Internet. Thatcher and Greyling (1998) had 51 University students and faculty members in South Africa with different amounts of experience with computers and the Internet draw mental models of the Internet to examine their conceptualization of it. Findings showed that the more experience participants had using the Internet the more complex were their conceptualizations. Similarly, Philleo (1995) had graduate students participate in a 5-week course to learn about the Internet. Afterwards, the graduate students were asked to draw a picture of their conceptualization of it. Students in the course showed a more complex understanding of the Internet than those not in the course. Levin, Stuve, and Jacobson (1999) later found differences in college students' understanding of the Internet that persisted after one semester of being exposed to it. Thus, direct experience with the Internet can lead to a slightly greater understanding of the Internet for adults. This line of research with adults yields results similar to those found among children, as presented above, and provides initial but interesting evidence for how children and adults understand the Internet as a unique concept.

THREE MAJOR STUDIES ON HOW INDIVIDUALS UNDERSTAND THE INTERNET

In a series of studies Yan (2005, 2006, 2009a) systematically investigated developmental differences in children's understanding of the Internet. In the first of these studies, Yan (2005) explored differences among children aged 5- to 12-years old (split into three groups: 5- to 8-year-olds, 9- and 10-year-olds, and 11- and 12-year-olds) and adults in their understanding of the technical and social complexity of the Internet. Participants completed a survey (for older children who had basic reading skills) or interview (for young children who did not yet have basic reading skills) concerning three variables: online experience, understanding of the technical complexity of the Internet, and understanding of the social complexity of the Internet. To examine the first variable, participants were asked about their experience with a variety of Internet applications, such as email, the number of years of experience with the Internet, and how often they used the Internet. To investigate their understanding of the technical complexity of the Internet, participants were asked open-ended questions such as "what is the Internet?," "where is the Internet?," and "how big is the Internet?" To explore their understanding of the social complexity of the Internet, the participants were questioned about the possible negative and positive social consequences and about safety concerns.

Based on whether and how much participants perceived the Internet perceptually or conceptually (a computer-like interface or a complex network system), participants' technical understanding as demonstrated through these surveys and interviews was coded as reflective of one of four levels: minimal (perception-based), partial (perception-bounded), extended (conception-bounded), and correct (conception-based). Minimal Understanding represented completely perception-based knowledge about the Internet. It was assigned to those who perceived the Internet as one computer (e.g., saying that Internet is a computer or drawing a picture of one computer). Partial Understanding represented perception-bounded knowledge about the Internet. It was assigned to those who perceived the Internet as either several computers with no indication of connections among them or simple connections of several computers (e.g., saying that the Internet has only two computers or drawing several computers connected with a straight line). Extended Understanding represented conception-bounded understanding of the Internet. It was assigned to those who considered the Internet a network-like system in which a computing center links with multiple computers (e.g., saying that the Internet is a network or drawing a picture of a computer network). Correct Understanding represented completely conception-based understanding of the Internet. It was assigned to those who correctly understood the Internet as a system with multiple connected networks, demonstrating a scientifically sound understanding of technical complexity (e.g., saying that the Internet is a network of networks or drawing a picture of multiple networks).

Like their technical understanding, participants' social understanding was coded at four levels: minimal (perception-based), partial (perception-bounded), extended (conception-bounded), and correct (conception-based). Minimal Understanding indicated that an individual knew very little about the positive or negative social consequence of the Internet (e.g., concerned only about the slowness of opening web pages) and expressed little precaution when using the Internet (e.g., claiming that the Internet would never hurt a person). Partial Understanding indicated that an individual had a general but limited sense of the positive or negative social consequences (e.g., reporting only 1–2 superficial social consequence(s) such as seeing too many popup advertisements and spending too much time in a chat room) and made reference to vague precautions related to using the Internet (e.g., believing that a bad thing could happen when emailing someone). Extended Understanding indicated a clear understanding of the profound social consequences of the Internet (e.g., discussing two or three important societal concern(s) such as online privacy or the digital divide) and a proper attitude towards Internet use (e.g., explicitly expressing precautions in using email and browsing websites). Correct Understanding indicated a balanced and comprehensive understanding of the profound positive and negative social consequences of the Internet (e.g., explicitly specifying various serious problems on the Internet, such as teenage pornography websites, stealing personal information, posting false advertisements, and online attacks by hackers) and a thoughtful attitude towards Internet use and online safety (e.g., discussing password protection and filtering programs), showing a scientifically sound understanding of the social complexity of the Internet.

As expected, there were significant differences among the age groups in online experience, with 11- to 12-year-olds and adults reporting the most experience and the 5- to 8-year-olds, the least. For understanding of the technical complexity, a significant difference between the 9- to 10-year-old group and the 11- to 12-year-old group was found as 68% of the former group showed a minimal understanding. Among the 11- to 12-year-old group, few showed a minimal understanding of the technical complexity (23%); the majority showed either partial (43%) or extended understanding (29%). Only two participants in the 11- to 12-year-old group and one adult showed correct scientific understanding of the Internet's technical complexity. For understanding the social complexity, significant age differences between the 9- to 10-year-old group and the 11- to 12-year-old group were found, as well as between the 11- to 12-year-old group and adults. Similarly, the majority of 9- to 10-year-olds (68%) showed a minimal understanding of the Internet's social complexity. However, the majority of 11- to 12-year-olds (53%) showed a partial understanding. Almost all adults showed either a partial understanding (36%) or an extended understanding (61%). Only one adult showed a correct scientific understanding of the social complexity of the Internet. These findings indicated that children showed development in their understanding of the complexity of the Internet between the ages of 9- to 12-years-old. However, even adults rarely showed a correct scientific understanding of the technical and social complexity of the Internet.

Furthermore, age and online experience were both significant predictors of understanding the technical complexity of the Internet, with age serving as a better predictor than experience. Thus, older children and adults generally showed significantly greater understanding of the technical complexities of the Internet than younger children did, while their online experience played only a secondary role rather than a primary one. However, for understanding the social complexity of the Internet, only age was a significant predictor. These findings highlight developmental differences in understanding the complexity of the Internet.

Yan (2006) then examined the relationship between age, online experience, and the understanding of the technical and social complexity of the Internet. He hypothesized that an individual's understanding of the technical and social complexity of the Internet would be influenced by factors including: direct online experience (e.g., years using the Internet, hours using the Internet per week), indirect online experience (e.g., experience gained through informal Internet classes or media exposure), demographic variables (e.g., age and gender), and psychological variables (e.g., reasoning and personality). Participants were fourth through eighth graders.

A symmetric reciprocal effect was not found between technical understanding and social understanding based on two key pieces of statistical evidence. First, a model with two reciprocal paths between technical understanding and social understanding showed a good fit to data, indicating that there existed some significant relationships between these two paths. However, neither of the reciprocal paths were found to be significant; note also that the path from social understanding to technical understanding was negative and much weaker. This model indicated that there were no symmetric reciprocal relationships between social and technical understanding of the Internet; otherwise, these two paths would have been statistically significant and relatively equal in their path coefficients. Second, after removing the weaker path from social understanding to technical understanding, the model showed both better fit indices and more parsimonious evidence, with a significant path from technical understanding to social understanding, $b_{\text{tech-soc}} = .197$, $p < .001$, indicating that children's understanding of the technical complexity of the Internet influenced their social understanding, but not vice versa. Thus, the Internet is a technological system, and understanding its technological complexity helps children understand its social complexity (e.g., knowing that the Internet is a gigantic system of various networks linking to millions of different users helps one to understand how cyber predicators could abuse the Internet in various sophisticated ways); however, understanding its social complexity may have no ramifications for understanding its technical complexity (e.g., hearing a scaring story about a cyber predicator might not automatically make one understand how complex computational networks work technically).

Age remained the most powerful predictor of Internet understanding. On average, children showed a partial understanding of the social and technical complexity of the Internet (Yan, 2005, 2006). Specifically, in terms of direct effects of age, both the path from Age to Technical Understanding and the path from Age to Social Understanding were statistically significant. Further, while there was no indirect effect of age on technical understanding, there were multiple indirect effects of age differences on social understanding through a variety of pathways (e.g., via Frequency of Internet Use, Internet Classes, and Technical Understanding). In short, older children showed a greater understanding of the social and technical complexity of the Internet than younger children. Further, children's understanding of the complexity of the Internet was more a reflection of their age than other factors related to Internet use, such as both the duration and frequency of Internet use, or having attended informal classes about the Internet. In contrast, no gender effects were found for either type of understanding. Collectively, Yan (2005, 2006) show that preadolescents show an adult level of understanding of the technical and social complexity of the Internet. However, correct scientific understanding of the complexity of the Internet remains rare. These findings conform to those addressing children's conceptual understanding of other natural, social, and mental systems, whereby their understanding becomes more sophisticated over the course of development (e.g., Carey, 1985; Keil, 1989; Wellman & Gelman, 1998).

The effect of age on understanding raises a more general issue seen in the study of conceptual development concerning how children learn to understand these very new and highly complex concepts. Because Yan's participants were raised in New York, a state with one of the highest Internet penetration rates in the country, many had four to five years of direct online experience at home and at school and also had attended at least one informal Internet class. This experience was likely self-guided (e.g., children learn about the Internet by themselves rather than from a good book) (Kuhn, 1989) and the social scaffolding provided by their parents may not have been optimal (Fischer & Bidell, 1998; Yan & Fischer, 2002), thereby limiting their understanding of the complexities of the Internet. Educational scaffolding as provided via Internet workshops offered by schools or public libraries also may not be effective for learning about the Internet (Dawson, 2002).

Similarly, the novel concepts to be learned may be too new to allow children to use their existing fundamental knowledge, such as fundamental concepts of theory of mind or early numbers (Wellman & Gelman, 1998), or core knowledge (Spelke, Breinlinger, Macomber, & Jacobson, 1992). Thus, children may rely on domain general resources, such as maturity, to enhance their understanding of the Internet (Carey, 1999).

Yan (2005, 2006) was limited because three types of criteria were used to assess participants' knowledge of the complexities of the Internet. First, the 2005 and 2006 studies compared understanding in relation to other age levels, which reflects a norm-referenced approach to assessment rather than a criterion-referenced approach to assessment (Cronbach, 1970; Glaser, 1963). Norm-referenced assessments are appropriate for examining differences across age groups (e.g., Kalish & Cornelius, 2007; Shtulman & Carey, 2007). However, they do not assess how well individuals actually understand the complexity of the Internet. Second, the reference system used to judge understanding was adults. Typically, adults represent the most sophisticated level of understanding in developmental research so they are a good reference group to use when determining the understanding of children and adolescents (Coley, 2000; Kelly & Church, 1998; Notaro, Gelman, & Zimmerman, 2001). However, the Internet appears to be a unique artifact in that adults may not hold correct scientific understanding of the Internet. This method again is a norm-referenced approach that measures children's understanding in comparison to adults but does not measure how well individuals actually understand the complexity of the Internet. Third, how correct their understanding of the Internet is was also used as a reference of understanding. This method is a criterion-reference approach since it compares the actual understanding of the Internet to a set of criteria. Different assessment approaches will lead to different conclusions. For instance, while the peer-referenced assessment suggested significant improvement across age, the adult-referenced assessment indicated adult-like understanding among children, and the correctness-referenced assessment suggested very limited understanding among both children and adults. Thus, the mixed use of three different assessment methods in the studies made it difficult to determine how well individuals understood the Internet.

In a follow-up study, Yan (2009a) chose to use correctness-referenced assessments to assess how well individuals understood the Internet among 786 participants, including children aged 9- to 17-years old and adults. Based on whether and how much participants perceived the Internet perceptually or conceptually (a computer-like interface or a complex network system), participants' technical understanding was coded at four levels: (1) Level 1 was Minimal Understanding, representing completely perception-based knowledge about the Internet which was assigned to those who perceived the Internet as one computer; (2) Level 2 was Partial Understanding, representing perception-bounded knowledge about the Internet. It was assigned to those who perceived the Internet as either several computers with no indication of connections among them or simple connections of several computers; (3) Level 3 was Extended Understanding, representing conception-bounded understanding of the Internet. It was assigned to those who considered the Internet a network-like system in which a computing center linked with multiple computers; and (4) Level 4 was Correct Understanding, representing completely conception-based understanding of the Internet. It was assigned to those who correctly understood the Internet as a system with multiple connected networks, demonstrating a scientifically sound understanding of technical complexity.

Like their technical understanding, participants' social understanding was coded at four levels: (1) Level 1 was Minimal Understanding, indicating that an individual knew very little about the positive or negative social consequence of the Internet and expressed little precaution when using the Internet; (2) Level 2 was Partial Understanding, indicating that an individual had a general but limited sense of the positive or negative social consequence, and a vague precaution related to using the Internet; (3) Level 3 was Extended Understanding and indicated a clear understanding of the profound social consequences of the Internet and a proper attitude towards Internet use; and (4) Level 4 was Correct Understanding, indicating a balanced and comprehensive understanding of the profound positive and negative social consequences of the Internet and a thoughtful attitude towards Internet use and online safety, collectively reflecting a scientifically sound understanding of the social complexity of the Internet.

There are two major findings of the study. First, no 9- to 13-year-olds showed correct technical understanding; only about 5% of 14- and 15-year-olds had correct technical understanding, and only 12% of 17-year-olds and adults had correct technical understanding. At all ages, a considerable number of participants showed minimal or partial technical understanding, essentially perception-based or perception-bounded knowledge about the Internet. Second, no 9- to 13-year-olds showed correct social understanding, except for one 11-year-old. Less than 5% of the 14- to 17-year-olds showed correct social understanding, and only 10% of adults showed correct social understanding. Again, at all ages, many participants showed limited social understanding, essentially perception-based or perception-bounded knowledge about the Internet.

These findings are surprising because of the vast experience these participants had had with the Internet, with many indicating that they use the computer on a daily or weekly basis and have attended multiple informal Internet classes. These findings are even more surprising because children show much lower levels of understanding the Internet compared to their levels of understanding of other concepts. A plethora of evidence indicates that children understand basic concepts in a variety of domains, such as physics, psychology, and biology in early childhood (e.g., Carey, 1985; Gopnik, Meltzoff, & Kuhl, 1999; Harris, Brown, Marriott, Whittall, & Harmer, 1991; Siegler & Thompson, 1998; Vosniadou & Brewer, 1992; Wellman & Gelman, 1998). Typically, this knowledge improves greatly during middle childhood (e.g., Carey, 1985, 1999; Hatano & Inagaki, 1994; Simons & Keil, 1995; Smith, Solomon, & Carey, 2005). Children then tend to have a correct understanding of normally unobservable scientific concepts and spiritual concepts by 10 years of age (Harris & Koenig, 2006). Most 9-year-olds have a conceptual understanding of the world around them, including their own brain, life, and earth. In contrast, Yan's work overall indicates that children's understanding of the Internet as a system with enormous technical complexity and social complexity may lag about 2 to 5 years behind their understanding of other concepts, since children in the study did not reach an adult-like understanding of the Internet until 12 to 15 years of age.

The lag phenomenon observed in these studies can be interpreted through the lens of developmental resources theory (Carey, 1999). According to this theory, there are basically two resources of information relevant for conceptual development, *internal* sources (e.g., mathematical-logic ability and perspective taking capacity, Piaget, 1983) and *external* sources (e.g., language competence and cultural knowledge, Vygotsky, 1978). The internal sources can be domain-*general* (e.g., metacognition) or domain-*specific* (e.g., knowledge in core domains, such as biology). The external sources can be attained through either *direct* experiences (e.g., daily life experiences) or *indirect* experiences (e.g., learning from testimony from adults).

As an internal resource for understanding the Internet, only age appears to be a direct dominant influence. As a new and emerging concept, there is a lack of domain-specific knowledge about the Internet, and domain-general knowledge may not be applicable to understanding the Internet given the mismatch between perceptual features and the conceptual reality of the

Internet. With respect to external resources, children, adolescents, and adults all have had plenty of direct experience with the Internet. However, these direct experiences tend to involve essentially a trial-and-error process, with much self-observation and self-exploration, but without good support and scaffolding. They do have access to various educational opportunities (such as through informal Internet classes) as a way to develop their indirect experience and to learn about the Internet. However, these indirect experiences are found to be an ineffective tool for learning about the complexity of the Internet.

Thus, given these unique circumstances, both children and adults are left to learn about the Internet only through their own internal domain-general resources. This has led to a surprisingly limited and perception-bounded understanding and knowledge about the Internet. In short, the limited internal and external resources likely lead to the limited understanding of the technical and social complexity of the Internet for both children, as exemplified in the 2- to 5-year lag in understanding the Internet compared to children's understanding of other concepts, and adults, as only few adults show a scientific understanding of the Internet.

CONCLUSIONS

In this chapter, we have synthesized empirical evidence, indicating that adults and children demonstrate a limited understanding of the technical and social complexity of the Internet and have limited resources to help them understand the Internet as a highly complex and newly emerged artifact. It is still a long way for the cognitive development community to develop a solid scientific understanding of how people understand the Internet. Nevertheless, this line of research might stimulate and motivate future developmental research in two major directions. First, within the area of artifact research, it should be particularly promising to conduct a series of comparative studies to examine individuals' understanding of a wide variety of artifacts, including simple artifacts (e.g., teapots or books) vs. complex artifacts (e.g., the Internet and mobile phones), existing artifacts (e.g., telephones and television) vs. emerging artifacts (e.g., the Internet of things or wearable devices), static artifacts (e.g., buildings and furniture) vs. moving artifacts (e.g., cars and airplanes), and biological artifacts (e.g., artificial hearts and artificial eyes) vs. nonbiological artifacts (e.g., solar systems and nanomaterials). A systematic developmental investigation of understanding artifacts can help build a new important research program, similar to the highly productive research programs of understanding the natural, social, and mental world in developmental science.

Second, in terms of cyber behavior, it should be critical to build a research program systematically examining three core areas of research: Internet understanding, Internet decision making, and Internet behavior among adults and children. To guide and protect Internet users, developmental researchers should examine how adults and children understand the Internet, and more importantly, explore how they make online decisions intuitively or rationally and eventually how they take actions in the cyber world. A few years ago just after he won the Noble Prize in Economics, Daniel Kahneman pointed out the special need for studying online intuitive and rational decisions as an emerging area (D. Kahneman, personal communication, April 16, 2008). These three areas of research are sequentially interconnected as the three major pieces of a chain of cyber behavior, from the top to the bottom. Developmental researchers should and will make unique and important contributions to this program by examining how people, especially young Internet users, develop their abilities over time in understanding the Internet, making decisions online, and taking actions in the cyberspace.

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