Technologizing Bronfenbrenner: Neo-ecological Theory

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Abstract

We propose an adaptation of Urie Bronfenbrenner's bioecological theory, *neo-ecological theory*. As bioecological theory was developed in the 20th century, it requires significant modifications to reflect some of the most ubiquitous contexts in which adolescents learn, play, and grow—the technological and virtual ones. Although several scholars have developed laudable theories related to youth development in virtual contexts, the field lacks an overarching theory to address the intersection of development and technology. In developing neo-ecological theory, we hold true to the tenets of bioecological theory, but suggest key modifications to reflect our technologized world. We delineate a key alteration to the microsystem, namely the existence of two types of microsystems—physical and virtual. In addition, we emphasize the importance of macrosystemic influences (i.e., the influences of culture and within-society subcultural variation) in understanding development in the digital age. The implications of these modifications cascade across the Process-Person-Context-Time (PPCT) model; proximal processes, person characteristics, context, and time are all reexamined. In the digital age, virtual microsystems are central contexts in which youth engage in proximal processes. As such, we believe that all scholars of development, regardless of their specific research interests, should consider the ways digital contexts influence their outcomes of interest. Without it, practitioners, policy makers, parents, and technologists will be in the dark about how best to support adolescents.

Keywords Bronfenbrenner's bioecological theory · neo-ecological theory · adolescent development · technology

Urie Bronfenbrenner developed his ecological theory of human development in response to what he described as "…the science of children in strange situations" (Bronfenbrenner, 1977, p. 513). We argue this critique is applicable today, as developmental and family sciences frequently overlook some of the ubiquitous contexts in which youth learn, play, and grow—the technological and virtual ones. Bronfenbrenner's theory, being fully developed by the turn of the century (Rosa & Tudge, 2013), did not consider the impact of developing in the digital age. Building upon bioecological theory, this paper proposes an innovative conceptual lens for understanding development in the digital age: *neo-ecological theory*. This adaptation is particularly applicable to researchers focused on the influences of technology in the lives of adolescents, but we contend that all scholars studying children, youth, and families should consider the extent to which digital contexts impact their outcomes of interest. Further, although the focus of this paper is primarily on youth, the influence of technology on human development arguably spans the life course.

Although the digital revolution may have begun with the advent of the personal computer, the introduction of smartphones (e.g., the iPhone in 2007) demarcated a new technological period particularly relevant to social scientists. In a prophetic 1991 paper, Weiser introduced the idea of ubiquitous technology, and stated that "the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (p. 94). Since 2007, this prophecy has been realized; digital technology is inextricably woven "into the fabric of everyday life." As digital technology has miniaturized, the boundaries between the *virtual* and *physical* realms are no longer clear (Uzelac, 2008). In addition to our phones, computers, and tablets, silicone chips exist in our cars, refrigerators, thermostats, light bulbs, vacuums, alarm clocks, and countless other devices. Smart home products listen to the cadence and content of our lives and their algorithms provide us with individualized information, products,

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and services. Computing has become ambient, such that the boundaries between what is or what is not technology is no longer readily apparent (Plowman, 2019). Further, interactions with technology are no longer individual and unidirectional, but complex, bidirectional, and dynamic.

In response to this digital revolution, a moral panic has ensued among parents, policy makers, practitioners, and researchers alike. Pathological and deficit-based approaches have proliferated, and media narratives and policy decisions have been made based on small effect sizes from cross-sectional studies (Ferguson, 2020). This moral panic constitutes a *moral imperative* for scholars of child and adolescent development, as the "true cost lies in the enormous loss of scientific knowledge and understanding of the role media play in development and developmental processes" (Vandewater, 2013, p. 50). We contend that a cohesive theoretical framework is essential to the development of high-quality and strengths-based research designs, where technology can be incorporated regardless of the specific field of inquiry.

The language of the digital age is messy; words like digital, media, online, virtual, technological, digital, the Internet, and social have permeated our lexicon and become so ubiquitous that it often becomes difficult to ascertain their intended meaning. Whereas this plethora of words is likely not a significant issue in day-to-day life, clearly defining these terms and constructs is necessary to advance scholarship in this area of research. Platforms are "mechanisms or technological vehicles for connecting people and information" (McFarland & Ployhart, 2015, p. 1654), and the basis for all digital software and their related communications, interactions, and activities. Platforms range from simple (e.g., text messaging) to complex (e.g., social media). Social media platforms are unique in that they "facilitate information sharing, user-created content, and collaboration across people" (p. 1653). Across these different platforms, the *content* is the text, images, video, and audio shared by its users. Subsequently, the ability to share, distribute, access, and interact with information is shaped both by the features of the digital platform and the content it is designed to promulgate. McFarland and Ployhart (2015) delineated a valuable taxonomy for organizing and understanding social interactions (and their related technologies) in the digital age—the omnibus context continuum. This continuum ranges from face-to-face (i.e., physical) interactions on one pole, through 'Web 1.0' (e.g., read- and write-only applications like text messaging and email) to 'Web 2.0' (e.g., interactive applications with programming features like social media) on the other. This continuum highlights how material, spatial and temporal differences impact the affordances of these environments. The non-digital end of the continuum exists in the physical world, where matter is made from atoms and interactions occur in the same spatial-temporal location (McFarland & Ployhart, 2015; Nesi et al., 2018a). The social

media end of the continuum exists in the virtual world, comprised of intangible bits of data where spatial and temporal restrictions are freed. Although not outlined in McFarland and Ployhart's paper, as their focus was on social media, we contend that most online gaming contexts lie closer to the Web 2.0 pole. Like social media platforms, multiplayer online games allow for interactions and activities with both other people and objects and symbols in the environment.

Bronfenbrenner's contributions to the field of child development spanned four decades (Tudge, 2017). Bronfenbrenner initially termed his theory "the ecology of human development" before revising it to "ecological systems theory" and finally to "bioecological theory." These iterations were developed across three distinct phases: (a) 1973-1979, (b) 1983-1993, and (c) 1993-2006 (Rosa & Tudge, 2013). Rather than describing the theory's development across these three phases (see also Tudge et al., in press), our "technologizing" adaptation is based on the final iteration of this theorizing, with one exception—the inclusion of the macrosystem from phase two. Of particular importance to our purpose are his writings on the role of cultures and sub-cultures, although they are not to be found in the final phase. In the second phase, Bronfenbrenner wrote:

> …human-beings are not only a culture-producing species, they are also culture produced; that is, the psychological characteristics of the species are a joint, interactive function of…an active organism…and…of the forms of psychological functioning and possible courses of development existing in a given culture at a particular point in history. (Bronfenbrenner, 1989, p. 204)

This point is relevant to our adaptation of bioecological theory because of the unprecedented (and rapidly evolving) cultural and historical era in which today's young people are developing. We argue that without acknowledgement and incorporation of these influences on development, developmental science will again become "the science of children in strange situations." In the third phase, bioecological theory added a fundamental concept—proximal processes—termed "the engines of development" (Bronfenbrenner & Evans, 2000, p. 118), and outlined the Process-Person-Context-Time (PPCT) research model. Bronfenbrenner and Morris (2006) elaborated on the synergistic and dynamic nature of the theory: "The combination of Person and Context exhibit a mutually reinforcing, multiplicative, indirect effect on the power of proximal processes as the engines of development" (p. 801).

This theoretical paper proposes a conceptual framework for understanding and researching development in the digital age. Our ideas have drawn both from bioecological theory and from theoretical work about technology and youth (e.g., Granic et al., 2020; Nesi et al., 2018a; McFarland &

Ployhart, 2015; Subrahmanyam & Smahel, 2010). Subrahmanyam and Šmahel proposed the co-construction model of adolescents' online behavior. This model centers on adolescents as the agentic co-creators of their own virtual environments. In addition, these scholars described virtual contexts as "cultural spaces, where norms are created, shared and passed on to other users. Online culture is not static, but is a cyclical dynamic entity, and users are constantly generating and passing on new norms" (Subrahmanyam & Smahel, 2010, p. 34). This model recognizes the important role digital sub-cultures play in the lives of adolescents. Nesi et al. (2018a, 2018b) challenged preconceptions that online interactions mirror offline ones and proposed that "the social media context *transforms* adolescents' peer experiences" (Nesi et al., 2018a, p. 268). Their "transformation framework" identifies key features and affordances of social media platforms that alter peer interactions and relationships in adolescence. Granic et al. (2020) explored adolescent identity development in the digital age. They proposed moving beyond how much time is spent online (i.e., screen time) to look at how and why digital interactions and activities impact identity development. Granic et al. proposed that by focusing on identity-formation processes, researchers "…can help pinpoint the digital experiences that will contribute to both healthy normative development as well as the emergence of serious mental health concerns" (p. 196).

Neo-ecological Theory

Although we view proximal processes as constituting the "engines of development" (Bronfenbrenner & Evans, 2000, p. 118), our discussion of neo-ecological theory begins with context to accommodate profound alterations related to the microsystem, which have cascading impacts throughout the other elements of the model. We will then consider the remaining three constructs of the PPCT model, namely person characteristics, time, and proximal processes.

Context

Despite the fact that, from the outset, Bronfenbrenner's theory was explicitly ecological, dealing with the synergistic interdependence of individuals and the contexts in which they lived, it has largely been treated as a theory of context. Portrayals of his theory as the individual surrounded by concentric rings of context are ubiquitous both in academic texts and on the web. Our concern with this portrayal (see Tudge, 2008; Tudge et al., 2009, 2016) should not be treated as signifying that context was not an important part of his model. It is a *very* important part, especially in exploring how the spatial and temporal freedoms of the digital era impact development.

Microsystem

Bronfenbrenner defined the microsystem as:

> …a pattern of activities, social roles, and interpersonal relations experienced by the developing person in a given *face-to-face setting* with particular physical, social, and symbolic features that invite, permit, or inhibit, engagement in sustained, progressively more complex interaction with, and activity in, the immediate environment. (Bronfenbrenner et al., 1996, p. 1645, italics added)

In other words, microsystems were considered to be physical locations where "face-to-face" proximal processes took place (e.g., home, school, or work). Many of the attempts to apply ecological theory to the intersection of technology, children, youth, and families continue to have conceptualized the use of information communication technology as an activity or interaction *within* a face-to-face microsystem (e.g., Arnott., 2016; Edwards et al., 2017; Jordan, 2004; McHale et al., 2009; Vandewater, 2013; Williams & Merten, 2011). Other scholars (e.g., Johnson & Puplampu, 2008; Plowman, 2016; Wang et al., 2010) have chafed at this limitation and attempted to find ways to explain the complexity digital technology adds to the microsystem—namely that many of the interactions and activities in which youth currently engage are *not* occurring face-to-face.

Johnson and Puplampu (2008) acknowledged how virtual spaces complicate Bronfenbrenner's model by lifting geographical limitations on interactions. They proposed the "techno-subsystem, a dimension of the microsystem," which includes "child interaction[s] with both living and nonliving elements of communication, information, and recreation technologies in immediate or direct environments" (p. 5). They proposed that this subsystem acts as a conduit for interactions or activities in the microsystem. However, such a sub-system could be accounted for within Bronfenbrenner's existing theory—namely the features of the microsystem (i.e., "particular physical, social, and symbolic features that invite, permit, or inhibit, engagement…" (Bronfenbrenner et al., 1996, p. 1645)). Plowman (2016) discussed the ways in which technological interactions can reach beyond the microsystem and argued that the "concepts of context influenced by Bronfenbrenner imply boundaries that may no longer exist" (p. 194). Instead, building on Dourish (2004) and Heritage and Clayman (2011), Plowman suggested that contexts may be more relational than spatial, but did not specify further how such a concept might relate to the rest of the model or be operationalized.

Digital technology has created a conceptual and methodological quandary for Bronfenbrenner's microsystem: If virtual interactions and activities are not happening in the microsystem, where *are* they happening? Neither the

solutions proposed by Johnson and Puplampu (2008) nor Plowman (2016) adequately answer this question. In our view, virtual interactions and activities are occurring in contexts unforeseen by Bronfenbrenner—in bits of data travelling at the speed of light—and his theory must be fundamentally altered to incorporate modern "…activities, social roles, and interpersonal relations" (Bronfenbrenner et al., 1996, p. 1645). As such, we propose the first of three modifications to the microsystem:

1. *There exist two types of microsystems: virtual and physical.*

   a. A *virtual* microsystem is a pattern of activities, social roles, and interpersonal relations experienced by the developing person on a given *digital platform* with particular relational and symbolic features that invite, permit, or inhibit, engagement in proximal processes within that environment.
   b. A *physical* microsystem is a pattern of activities, social roles, and interpersonal relations experienced by the developing person in a *face-to-face setting* with particular physical, social, and symbolic features that invite, permit, or inhibit, engagement in proximal processes within that environment.

Although some may argue that such a proposition is unnecessary and the simple removal of the phrase "face-to-face" from the definition would be sufficient to resolve the problem, we believe it is crucial to make a distinction between these two types of microsystems because virtual and physical microsystems each have unique "physical, social, and symbolic features" that differentially impact the synergistic interrelation of proximal processes, person characteristics, and time. We also conceptualize two types of microsystems because spatial constraints have been lifted, allowing for the second of our three modifications:

2. *The developing individual can exist in more than one microsystem at once.*

Whereas Bronfenbrenner conceptualized microsystems as discrete physical locations, like the home, school, or workplace, the flexibility of digital platforms enables individuals to participate in interactions within two microsystems simultaneously. Take as examples a child attending classes remotely from their home, college students playing online games with friends from their dorm room, a parent sharing a photo on a social media platform with their child while at work, or an older adult in an assisted-living facility video conferencing with their family who live in another country. All of these individuals are participating in two microsystems—the virtual one (e.g., an online classroom) and the physical one (e.g., their home). Further, we specify more than one microsystem to reflect ubiquitous *media multitasking* (i.e., the use of more than one digital platform simultaneously, Rideout et al., 2010). As such, developing individuals can participate in two or more virtual microsystems (e.g., attending a online meeting while scrolling through a social media feed) in addition to their physical microsystem (e.g., the home).

As spatial and temporal constraints have been lifted in virtual microsystems, the ways in which individuals move in and out of them is different than in physical microsystems. Traditionally imagined, one enters a physical microsystem (e.g., the home) through a door and exits the same way. This is different from a child's or adolescent's virtual microsystem, such as an online multiplayer game. The child's presence in this virtual microsystem is defined by the interactions and activities in which the child is engaged—playing a game with their peers. As elucidated by Dourish (2004), "context isn't just 'there,' but is actively produced, maintained and enacted in the course of the activity at hand" (p. 22). Virtual microsystems are phenomenological; persons appear to 'open' and 'close' virtual microsystems through the interactions and activities in which they engage, regardless of the software itself being loaded on their gaming console. The same principle applies to virtual microsystems on social media platforms; a teenager opens a virtual microsystem when they scroll through social media and closes this microsystem when they move to a different platform or put down their device. In summary, this third modification can be stated as:

3. *The opening and closing of virtual microsystems are defined by the interactions and activities in which the developing individual engages.*

Unique Features of the Virtual Microsystem The features outlined below are not shared by all virtual microsystems, nor inapplicable to physical microsystems. Instead, in line with the omnibus continuum framework proposed by McFarland and Ployhart (2015), we propose that these features be viewed on a continuum, both in terms of their applicability and degree of pertinence to the microsystem in question. Given the breadth and pace of technological innovation (not to mention the corresponding youth-led cultural innovation in digital spaces), scholars must be flexible and dynamic in their approach to describing virtual microsystems. We suggest these features as a starting place for incorporating elements of virtual microsystems into research, not as a definitive list.

Synchronicity and Asychnronicity Interactions and activities in virtual microsystems can take place both synchronously (e.g., in real time) and asynchronously (e.g., with a time lag) (Best et al., 2014; McFarland & Ployhart, 2015). Some activities and interactions in physical microsystems are asynchronous (e.g., letter writing). Nonetheless, this feature is more pronounced in virtual microsystems, although the degree of asychnronicity varies depending on the digital platform (Nesi et al., 2018a). Some virtual microsystems are highly synchronous (e.g., video conferencing, online gaming) whereas email is asynchronous. Other platforms incorporate elements of both, allowing individuals to engage with content and in communication in real time (e.g., instant messaging and watching live video streams) and with previously posted content or communications (e.g., social media feeds). The asychnronicity of virtual microsystems can create more opportunities for adolescents to engage on their terms (Granic et al., 2020).

Availability Inherently, in flouting the spatial and temporal restraints of physical microsystems, individuals in virtual microsystems can interact with others at great distances, both synchronously and asynchronously (McFarland & Ployhart, 2015). Availability is a key affordance when considering proximal processes occurring in virtual microsystems, as it allows people to connect with others who may otherwise be unavailable to them (boyd, 2010; Nesi et al., 2018a). The relevance of availability to child development cannot be understated; it is central to the lives of young people in the digital age. For example, young people can connect with others who may have similar interests or be experiencing similar challenges (e.g., adolescents playing online games with friends who have moved away, LGBTQ youth seeking support on coming out to their family and community, etc.). During the COVID-19 epidemic, availability has become central to the functioning of society: children and youth attended school remotely, doctors ministered to their patients via online portals, and work meetings took place virtually.

Publicness Few physical microsystems allow young people to interact with large numbers of people. Even in a school or sports setting, "visual and auditory information is limited by physics; walls and other obstacles further restrain visibility" (boyd, 2008, p. 125). Larger venues, like concert halls or sports stadiums, are *not* microsystems (unless one happens to be a performer or play sports) because they do not allow for "sustained, progressively more complex interaction" (Bronfenbrenner et al., 1996, p. 1645) on a regular basis. In virtual microsystems, group interactions are not limited to a geographical location and individuals can communicate and interact with a much wider audience (Nesi et al., 2018a). Termed *networked publics* by boyd (2008), social media and interactive platforms "allow people to gather for social, cultural, and civic purposes and they help people connect with a world beyond their close friends and family" (boyd, 2010, p. 39). The feature of publicness is particularly relevant to scholars examining civic engagement among youth (Granic et al., 2020). In networked publics (e.g., social media platforms like Twitter), individuals are interacting with an *invisible audience* (boyd, 2008); individuals cannot know with certainty who or when others will read, view, or share the content they posted. As a result, how individuals imagine their 'audience' impacts their self-presentation (i.e., demand characteristics) in virtual microsystems.

Permanence Also termed persistence (boyd, 2008, 2010), this feature reflects the degree to which virtual interactions and activities remain accessible after the interaction is completed (Nesi et al., 2018a). Regardless of the synchronicity of the initial interaction or activity, their content can be accessed for an indefinite period of time. Permanence plays out differently depending on the digital platform and presents both opportunities and risks to development. Comments on social media platforms, websites, and blogs can remain indefinitely, and although some can be removed by the individual, others cannot, depending on who posted them and the affordances of the platform. Even platforms eschewing permanency face the conundrum of screenshots; content can be recorded and reshared, sometimes to the detriment of the original poster. As such, though an individual's "…attitudes and opinions may change over time, prior expressions of these attitudes and opinions that are expressed over social media still exist" (McFarland & Ployhart, 2015, p. 1659).

In conjunction with *searchability* (i.e., the ease with which people can find and verify information online; boyd, 2008; McFarland & Ployhart, 2015) this side of permanence can be detrimental and burdens today's youth in ways unexperienced by previous generations (Granic et al., 2020). Today's adolescents do not have the luxury of a 'fresh slate' when they change locations, schools, or workplaces; as virtual microsystems are not bound by geography or time, their digital past is omnipresent. News media reports of these incidents abound. For example, there have been reports of college acceptances and job offers rescinded because of comments or photos posted years earlier, adolescents devastated by intimate photographs and videos posted by angry former partners, and transgender youth outed by others who locate and repost digital evidence of their transition. The *scalability* (i.e., the ease with which content can be shared and disseminated to a wider audience; Boyd, 2010) of online content can magnify how permanence impacts proximal processes. However, the permanence of digital platforms can confer benefits as well; reminiscing and nostalgia are encouraged by looking back over photographs, videos, and interactions from the past, and may assist youth in developing their narrative identity (Granic et al., 2020).

Cue Absence Building upon cues-filtered-out theory (Culnan & Markus, 1987), Nesi et al. (2018a) elucidated cue absence as a transformative feature of social media contexts. Unlike in physical microsystems, where typically a combination of verbal and non-verbal cues informs interactions, interpersonal cues in virtual microsystems may be more limited. Interpersonal cues in virtual microsystems are on a continuum, dependent on the design of the digital platform. Most video chatting platforms allow participants to read voice and visual cues. Messaging platforms are text and image based, and content must be interpreted without tonal or visual cueing. In addition to audiovisual clues, identity is also a cue in interpersonal interactions (Nesi et al., 2018a), ranging from interactions with known persons, to *source anonymity* (i.e., personal identity is totally obscured; Valkenburg & Peter, 2011).

Additional Features In addition to these more prominent features of the virtual microsystem, there are additional features that may be relevant for some lines of research. In virtual microsystems, content (text, images, video, or audio) can be copied exactly as it was originally expressed. Termed *replicability* (boyd, 2008), this feature presents a striking contrast to physical microsystems, given that content (including photos and videos) can be shared verbatim instantly across wide distances (Nesi et al., 2018a). In a home or school microsystem, a story or information must be interpreted and then written down or remembered by a person before being re-told. However, in virtual microsystems individuals can share content verbatim with or without attribution. Content may also be altered and misattributed. In addition, virtual microsystems may possess a greater degree of *visualness* (i.e., the extent to which photographs and videos are emphasized on a digital platform, Nesi & Prinstein, 2018) than physical microsystems. Virtual microsystems also allow for interactions and activities to be quantified into metrics (e.g., numbers of likes, share, retweets). The *quantifiability* available on many digital platforms influences when, what, and how frequently adolescents engage in proximal processes in digital microsystems (Nesi & Prinstein, 2018).

Finally, we encourage researchers and practitioners to consider how machine learning and algorithms shape virtual microsystems. Algorithms on digital platforms are designed to gather and interpret data about all aspects of our lives (e.g., our skills, likes, routines, challenges, habits, geographical location) and subsequently tailor our experiences in accordance with goals determined by individuals in the exosystem (e.g., software developers, marketers, and investors). As such, virtual microsystems are a dynamic, individualized, and co-constructed context: "…information and communication processing hardware and software, alongside humans and other agents, collaboratively produce space and culture" (Taffel, 2014, p. 332). In this way,

exo- and macrosystemic forces exert considerable influence on the virtual microsystems of youth, often circumventing parents and educators.

Mesosystem

Unlike the microsystem, to which we made two key modifications, we contend that Bronfenbrenner's conceptualization of the mesosystem needs no adaptation to fit into neo-ecological theory. Bronfenbrenner defined the mesosystem "…as comprising the relationships existing between two or more settings; in short, it is a system of two or more microsystems" (Bronfenbrenner & Morris, 2006, p. 817). In some ways mesosystemic influences are even more important in neo-ecological theory, as "adolescents' physical, social, and digital worlds are intertwined and interconnected and have a transactional or bidirectional relationship with each other" (Subrahmanyam & Smahel, 2010, p. 35).

From a strengths-based perspective, mesosystemic-level research may illuminate whether skills learned in virtual microsystems translate into gains in physical contexts. Granic et al. (2020) elucidated examples of ways in which video games can help adolescents develop a sense of agency: intermittent reward schedules, micro-successes, the "hero's journey," and redemptive narratives. Although not explicitly utilizing an ecological perspective, a number of studies have examined mesosystemic influences between positive proximal processes in virtual and health outcomes in physical microsystems. In a study of African American and Latinx youth, Stevens et al. (2016) found that participants saw social media as an important and credible sources of sexual health information. Participants' exposure to sexual health information on social media was significantly associated with reductions in sexual risk-taking behaviors offline. Huang et al. (2013) and Suffoletto et al. (2014) found that web- and text-based drinking interventions reduced the incidence of binge drinking among adolescents. Bliuc et al. (2020) found that, for adults who suffer from alcohol and drug addiction, participation in online support groups on a regular basis for an extended period of time predicted positive recovery outcomes. They hypothesized that the participants' participation in an online recovery community (a virtual microsystem) helped individuals to build "recovery capital" (a person characteristic), which translated into lower rates of relapse in the physical microsystems they inhabited.

There are numerous studies of deleterious influences of virtual microsystems (see Nesi et al., in press, for a comprehensive overview); we will provide two examples of longitudinal mesosystemic studies. In their 2018 study, Nesi and Prinstein delineated a novel proximal process—digital status-seeking (i.e., "attempts to obtain social-media-based indicators of peer status (e.g., likes, comments)" (p. 1)—and
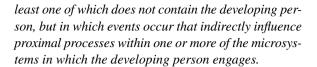
differentiated it from its physical microsystem counterpart, popularity. They found that adolescents who engaged in more digital status-seeking at baseline were more likely to engage in higher levels of substance abuse and have more sexual partners one year later. In their longitudinal study of Norwegian youth, Erevik et al. (2017) found that more frequent posting of and exposure to alcohol-related content on social media was predictive of later alcohol use, but this effect was weakened considerably when baseline alcohol use was taken into account. These studies did not measure proximal processes in both microsystems (as a true mesosystemic study would); nonetheless, they demonstrate complex interrelations between virtual and physical microsystems, and how important this system of systems is to a neo-ecological approach.

In addition to studies of the interrelation between virtual and physical microsystems, researchers should consider the mesosystemic relation between two or more virtual microsystems. Marwick and boyd (2011) described the phenomenon of *context collapse,* whereby multiple audiences (as imagined by the developing individual) converge on a single digital platform. For example, social groups that inhabit separate physical microsystems (e.g., colleagues in a workplace microsystem and family members in a home microsystem) may all be present in a single virtual microsystem (e.g., a social media platform). Alternately, social connections originating from different virtual microsystems (e.g., friends from an online support group and a romantic partner on a dating app) may each find the developing individual on a social media platform. These *collisions* of social interactions and activities from different microsystems presents challenges for how individuals represent themselves and their relationships with others. Without distinction between virtual and physical microsystems, mesosystem level analyses will be ineffectual and obscure the bidirectional and interrelated nature of these microsystems.

Exosystem

Similar to the mesosystem, the exosystem in neo-ecological theory remains largely unchanged from Bronfenbrenner's conceptualization. Bronfenbrenner (1993) defined the exosystem as "…the linkages and processes taking place between two or more settings, at least one of which does not contain the developing person, but in which events occur that indirectly influence processes within the immediate setting in which the developing person *lives*" (Bronfenbrenner, 1993, p. 24, italics added). However, we propose the wording of his definition be changed to reflect the duality of virtual and physical microsystems:

> An exosystem represents the linkages and processes taking place between two or more microsystems, at least one of which does not contain the developing person, but in which events occur that indirectly influence proximal processes within one or more of the microsystems in which the developing person engages.

More simply, exosystemic forces parallel those of the mesosystem; it is a system of systems, one of which does not contain the developing individual. In the digital age, exosystemic forces are likely a more significant force in the lives of youth than in previous generations. Rather than influencing youth through their home or school microsystems, where parents and teachers can potentially buffer (or at least discuss) deleterious exosystemic forces (e.g., the loss of a job, changes in school policies), exosystemic forces may impact youth participating in virtual microsystems more directly. For example, conflicts between software developers and hardware companies about pricing and revenue streams can indirectly impact adolescents' ability to engage in interactions and activities in virtual microsystems (e.g., #FreeFortnite, when Fortnite was removed from the Apple app store in 2020). In addition, decisions made in distal microsystems may impact who is present within virtual microsystems (e.g., Twitter's decision to permanently ban Donald Trump in January 2021).

This is an especially important level of context for developmental and social scientists to consider—our power to promote positive youth outcomes must now expand beyond our partnerships with parents, educators, and other practitioners to include developers of digital platforms. This a crucial exosystemic influence in the lives of youth and, as Granic et al. (2020) eloquently argued:

> If psychological scientists begin to partner and participate more in the development of digital tools of all kinds, they will have a better chance to provide young people with safe, enriching, identity-relevant online environments that feel authentic and relevant to their core needs and values. (p. 215)

Macrosystem

In his phase III writings, Bronfenbrenner and his colleagues (e.g., Bronfenbrenner et al., 1996) discussed at length the "growing chaos" in the United States, the result of a "major breakdown specifically in the domain of social development" (Bronfenbrenner & Evans, 2000, p. 121). Writing from a largely deficit-based perspective, Bronfenbrenner delineated this chaos as evident in two trends: (a) increasing time spent alone by children and adolescents, and (b) a "progressive decline in measures of competence and character" (p. 120). Bronfenbrenner saw these societal changes as deleterious, the fault of corrupting influences of single parenthood and disengaged youth. Rereading these paragraphs today underscores Bronfenbrenner's own positionality and calls

into question whether his earlier conceptualization of the macrosystem, as a "societal blueprint for a particular culture, subculture or other broader social context" (Bronfenbrenner, 1989, p. 228), was an enduring or transient element of his theory. Was this blueprint intended to be malleable and reflect changes in social norms? Or was this blueprint merely a mechanism for reinforcing the status quo? His later writings favor the latter, and in publications about bioecological theory and the PPCT model, the macrosystem is almost entirely absent.[1] Perhaps his own positionality and focus on social policy obscured him from viewing some of these changes (e.g., what he called "chaos" and a "teenage syndrome" (Bronfenbrenner & Morris, 2006, p. 824)) as being normative within a new cultural era (i.e., a time of shifting gender roles and less restrictive sexual mores).

As developmental and social scientists in the digital age, we would be wise to not follow suit. To understand and support today's young people, we must be prepared to examine the diverse cultures and subcultures within which they live, play, and grow. Only through incorporating the dynamic influences of the macrosystem can our research stay relevant to parents, educators, practitioners, and industry. To reflect the importance of the macrosystem to neo-ecological theory, we instead utilize Bronfenbrenner's earlier phase II writings in our interpretation of the macrosystem. In 1989, Bronfenbrenner defined the macrosystem as:

> …the overarching pattern of micro-, meso-, and exosystems characteristic of a given culture, subculture, or other broader social context, with particular reference to the developmentally-instigative [sic] belief systems, resources, hazards, life styles, opportunity structures, life course options, and patterns of social interchange that are embedded in each of these systems. (p. 228)

Further, we incorporate Tudge's *cultural-ecological theory* (Tudge, 2008) into our conceptualization of the macrosystem and its role within neo-ecological theory. Competence, which Bronfenbrenner delineated as "the demonstrated acquisition and further development of knowledge, skill, or ability to conduct and direct one's own behavior across situations and developmental domains" (Bronfenbrenner & Morris, 2006, p. 803), must be viewed as a culturally defined construct (Tudge, 2008). Tudge defined culture as:

> A group of people who share a set of values, beliefs, and practices; who have access to the same institutions, resources, and technologies; who have a sense of identity of themselves as constituting a group; and who attempt to communicate those values, beliefs, and practices to the following generation. (pp. 3–4)

This definition does not specify the type of group—it can refer to an entire society or to any group within that society that fits the definition. Obviously, this view of culture does not permit a single way in which to measure either competence or dysfunction, which can only be related to the cultural group's values and practices.

The ubiquity of digital technology is a global phenomenon; five billion people, roughly three-quarters of the world's population, owned smartphones in 2021. Smartphone ownership in emerging economies has skyrocketed in recent years, with youth being the most rapid adopters (Taylor & Silver, 2019). This rapid adoption of digital technology likely differentially impacts the development of adolescents depending upon the values and beliefs, resources, and social structure of their society. For example, Borzekowski et al. (2006) found that Ghanaian youth from lower socioeconomic backgrounds were more likely to use the internet for health information. Such a finding may run contrary to expectations based on higher rates of digital device ownership among higher socioeconomic youth, but when viewed within cultural norms of privacy related to sexual activity and health, this finding reveals that the internet is an important tool for providing health education to youth who leave school early to support their families and cannot access school-based health information.

Of additional consideration to social scientists is governmental censorship of the internet. The internet is sometimes viewed as a tool of liberation, and yet "The world's authoritarians have shown just as much aptitude for technology as their discontented citizens" (Lake, 2009). For example, the Great Firewall (Yang, 2020) of China exerted, at least through 2021, considerable restrictions on the form and content of digital technologies Chinese citizens can access. This censorship impacts the features of the virtual microsystems in China (e.g., anonymity is low), and as such, indirectly influences proximal processes. How might such restrictions and oversight impact identity development for Chinese adolescents? Iran, where all telecommunications are centralized by state-run agencies, maintains stringent controls over internet usage, prohibiting access to non-Islamic content (Iran, 2020). Such macro-level "hazards" (Bronfenbrenner, 1989, p. 228) may limit digital participation, but when viewed from the perspective of the culture itself, censorship may be viewed as a different formulation of cyberspace (Jiang, 2012) rather than a hazard.
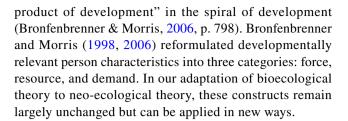
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[1] The term *macrosystem* is mentioned once in Bronfenbrenner and Morris (2006) on page 796, in reference to his 1979 book, despite references elsewhere to racial and ethnic differences within the United States. It is not mentioned at all in his 2000 publication with Evans, entitled, ironically, "Developmental Science in the 21st Century." Further, in a 1999 chapter, in which the term *macrosystem* also fails to appear, he concluded the section on micro-, meso-, and exosystem effects as follows: "So much for environmental process and context as shapers of development" (p. 20).

In addition to these societal-level variations, macro-level contexts also include within-society cultural groups. In the United States, the oppression and marginalization of people of color influences proximal processes in both physical and virtual microsystems and in the mesosystemic relations between them. In a qualitative study with African American and Latinx youth living in disadvantaged neighborhoods, Stephens and colleagues (2017) explored the myriad ways in which interactions and activities in virtual microsystems, like Facebook, can be both positive and negative. The "misuse of platforms can prove detrimental, leaving youth at the margins with another closed avenue to building community…youth are strategically migrating to social media sites with more restrictions as a way to limit their exposure to drama" (p. 964). Brock (2012) explored discourse on Black Twitter, which he described as a "public group of specific Twitter users" (p. 545). Twitter's rapid adoption as a vehicle for cultural communication and connection reflects the availability and publicness of the platform: "…transcending the size limitations and conversational incoherence of chat rooms, [Black Twitter allows] users to participate in open-ended community building discourses in near real-time" (p. 545). Virtual microsystems are not homogenous; macrosystemic influences extend into digital spaces, synergistically interacting with time, person characteristics, and features of the micro-, meso-, and exosystems.

Access to digital technology and broadband internet access is also influenced by macrosystemic influences. At the macrosystem level, this *digital divide* reflects class inequalities and disparities between urban and rural areas in the United States. The ramifications of the digital divide were amplified during the COVID-19 pandemic, as youth with limited access to digital devices and high-speed broadband were further disenfranchised when schooling went online (Beaunoyer et al., 2020). In addition to social isolation, health information about COVID prevention, testing, and vaccines was primarily transmitted through digital media, making lower socioeconomic and rural youth more vulnerable to the virus itself (Beaunoyer et al., 2020). Recent research suggests that the digital divide may not be as relevant to adolescents as to other populations (e.g., older adults), as access to smartphones is high across class groups (George et al., 2020). However, George et al. (2020) found that youth from more economically disadvantaged backgrounds were more likely to experience negative spillover between virtual and physical microsystems.

Person Characteristics

Person characteristics feature twice in bioecological theory, initially as one of the forces impacting proximal processes and again as a developmental outcome. Person characteristics are both "an indirect producer and…a product of development" in the spiral of development (Bronfenbrenner & Morris, 2006, p. 798). Bronfenbrenner and Morris (1998, 2006) reformulated developmentally relevant person characteristics into three categories: force, resource, and demand. In our adaptation of bioecological theory to neo-ecological theory, these constructs remain largely unchanged but can be applied in new ways.

Force

Force characteristics are "active behavioral dispositions" (Bronfenbrenner & Morris, 2006, p. 810) that promote or impede proximal processes. As such, force characteristics can be broken down further into developmentally generative (e.g., curiosity, agency, ability to delay gratification) and developmentally disruptive (e.g., impulsiveness, distractibility, inability to delay gratification) characteristics. Research has shown that behavioral dispositions can influence individuals' selection and use of digital platforms. For example, persons with more extroverted tendencies prefer to use platforms with more cue presence and eschew anonymity (Best et al., 2014).

Resource

Resource characteristics are "biopsychosocial liabilities and assets" (Bronfenbrenner & Morris, 2006, p. 812) that influence the capacity to engage in proximal processes—both positive and inverse (Merçon-Vargas et al., 2020). "Assets" include skills, knowledge, and abilities that promote competence and buffer against disruption, whereas "liabilities" describe characteristics like illness, social impairments, and physical disabilities. Adolescents may utilize skills and knowledge they gain from virtual microsystems in interactions with parents, teachers, and others in their physical microsystems. Youth are often the experts when it comes to information technology, and this can upend traditional hierarchies in homes and schools—providing opportunities for parents and teachers to learn from adolescents and further support their development as agentic and capable individuals (Barron et al., 2009; Bond, 2014; Nesi et al., 2018a). Although this may change as future generations of parents will have grown up with social and digital media, it is likely that technological innovation will introduce new challenges for parents of the future. Digital literacy (i.e., the ability to find and evaluate online information) is also a resource characteristic, but the digital divide may impair the development of this skillset, furthering disenfranchisement and isolation, and thus reinforcing the "digital vicious cycle" (Bronfenbrenner & Evans, 2000, p. 2).

Demand

Demand characteristics describe more phenotypic or observable features that "invite or discourage reactions" (Bronfenbrenner & Morris, 2006, p. 812) from the environment (e.g., gender, skin color, age, attractiveness, shyness, and happiness). Of all three types of characteristics, demand characteristics are possibly the most impacted by the advent and utilization of digital media. In virtual microsystems, developing individuals have tools (e.g., visualness, anonymity), time (e.g., asychnronicity), and space (e.g., availability) to regulate their online demand characteristics and, as a result, may have a greater degree of control in how they are perceived than in physical microsystems. Marwick and boyd (2011) posited that digital social performances are based on an individual's "imagined audience" (p. 115). Social performances can be curated using photographs, text, videos, design, social connections, and quantifiable metrics (e.g., "likes," shares). These performances also vary based on the digital platform. For example, profiles on dating sites and applications allow for highly curated self-presentations under optimal conditions (Marwick & boyd, 2011). However, social media platforms (e.g., Twitter, Snapchat) allow for more a more "dynamic, interactive identity presentation" (Marwick & boyd, 2011. p. 116). The visualness of some digital platforms (e.g., Instagram) may encourage more visual representations of self, as opposed to more narrative, text-based contexts. Although virtual microsystems allow for more curation of demand characteristics, these presentations can be limited by mesosystemic forces, as friends, family, and colleagues can be audience members in both virtual and physical microsystems (boyd, 2008).

Time

Although Bronfenbrenner had written about the importance of historical time in the first two phases of the theory, only during the third phase was time formally added to his Process-Person-Context-Time model. He described three types of time that impact development: micro-, meso-, and macrotime (termed the "chronosystem" during the second phase).

Microtime

Microtime is defined as "continuity versus discontinuity in ongoing episodes of proximal process" (Bronfenbrenner & Morris, 2006, p. 796), and refers to what is happening within a proximal process. Microtime parallels the construct of mindfulness: Is the developing individual able to stay present or 'in the moment' during a proximal process? Or is the proximal process being interrupted repeatedly? When framed from this perspective, microtime becomes an incredibly important component of neo-ecological theory.

As discussed previously, digital technology facilitates media multitasking, defined as the use of more than one digital device or platform simultaneously. Further, in our model, we propose that developing individuals can be in more than one microsystem at a time. Consequently, the ability of youth to stay present and engaged in proximal processes may be interrupted frequently. Digital platforms are designed to engage us; we receive messages and notifications when we get an email, a 'like' on social media, an upcoming event on our calendar, and when the refrigerator door is left ajar. The impact of some of these digital interruptions, also termed *technoference*, has been studied in both spousal and parent–child interactions. Using the actor–partner interdependence model to assess bidirectionality between parents, McDaniel and Radesky (2018) found that maternal (but not paternal) technoference in parent–child interactions significantly predicted higher levels of externalizing and internalizing child behaviors. Kushlev et al. (2016) found that adult participants assigned to a week-long experimental condition to maximize their phone's notifications reported significantly higher levels of inattention.

Mesotime

Mesotime refers to the repetition of proximal processes, over days, weeks, and years. Though not typically a focus in writings about the ecological model, mesotime is the only sub-element of the PPCT model to be explicitly described within the definition of proximal processes, which states: "To be effective, the interaction must occur on a *fairly regular basis* over extended periods of time" (Bronfenbrenner & Morris, 2006, p. 797, italics added). In future research utilizing neo-ecological theory, scholars should not consider time primarily in terms of interruptions to proximal processes, but rather examine how digital technology may both encourage and disrupt engagement in proximal processes on a regular basis. Some of the features of virtual microsystem may make it more possible for proximal processes to happen regularly, and over an extended period of time. For example, a young child may be able to read books each night on a video chatting platform with her grandparents who live far away. During COVID-19, students were able to attend school daily, avoiding severe disruptions in educational proximal processes because of digital classroom platforms.

However, paralleling technoference at the microtime level, digital technology may also impair the ability of individuals to engage in proximal processes on a regular basis. Virtual microsystems likely have an opportunity cost; youth may be missing out on proximal processes (e.g., learning a new sport) that occur in physical microsystems by engaging in e-sports. Alternatively, this opportunity cost may also be positive; fewer adolescents are engaging in sexual
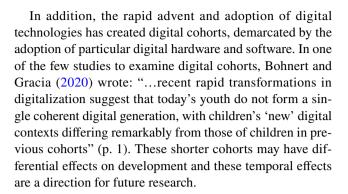
risk-taking behaviors than previous generations (Twenge et al., 2017).

Mesotime is also relevant to research about screen time. A full review of this expansive and contested literature is not within the scope of this paper (see Odgers & Jensen, 2020 for a recent review); nonetheless, we feel it is imperative to note that screen time is but one sub-element of the synergistic and interrelated influences on development in the digital age. Rather than focus solely on the length of time or frequency that adolescents spend in virtual microsystems, we recommend that scholars instead examine the frequency and durations of proximal processes occurring within virtual microsystems. Screen time is not a proxy for the pattern of proximal processes in which youth engage in online and is too simplistic to account for developmental outcomes. Bronfenbrenner eschewed focusing on direct effects, and instead suggested that "in ecological research, the principal main effects are likely to be interactions" (Bronfenbrenner, 1979, p. 38). A singular focus on screen time as a main effect obscures proximal processes and the underlying mechanisms of development. Granic et al. (2020) suggested that "Instead of simple frequency counts on different devices and application, what we need to examine is how the function of digital media relates to mental health" (p. 198).

Macrotime

Macrotime represents "the changing expectations and events in larger society, both within and across generations, as they affect and are affected by, processes and outcomes of human development over the life course" (Bronfenbrenner & Morris, 2006, p. 796). A such, macrotime and the macrosystem are two sides of the cultural coin. The bidirectionality between the macrosystem and developing individuals is more fluid now than at any time in history.

The advent of the internet and networked publics (boyd, 2008) has magnified and accelerated cultural change. Building upon Vygotsky (as did Bronfenbrenner), Greenfield and Yan (2006) wrote: "The internet is cultural because it is shared, norms are developed, and these norms are transmitted to new generations of users, even as the new users, greater access, and technological innovation create new norms" (pp. 392–393). Further, boyd (2008) argued that the internet has allowed adolescents to take back control of youth culture. For decades, decisions in the exosystem (by adults in positions of authority) have co-constructed a paradoxical youth culture where "the contradictions run deep—we sell sex to teens but prohibit them from having it; we tell teens to grow up but restrict them from the vices and freedoms of adult society" (p. 135). The advent of the internet freed adolescents and "decentralized publics" (p. 135), allowing them to participate more fully in co-constructing elements of the macrosystem.

In addition, the rapid advent and adoption of digital technologies has created digital cohorts, demarcated by the adoption of particular digital hardware and software. In one of the few studies to examine digital cohorts, Bohnert and Gracia (2020) wrote: "…recent rapid transformations in digitalization suggest that today's youth do not form a single coherent digital generation, with children's 'new' digital contexts differing remarkably from those of children in previous cohorts" (p. 1). These shorter cohorts may have differential effects on development and these temporal effects are a direction for future research.

Proximal Processes

Bronfenbrenner delineated proximal processes as the driving force behind human development in the third phase of the development of bioecological theory. Bronfenbrenner and Morris (2006) wrote:

> …human development takes place through processes of progressively more complex reciprocal interaction between an active, evolving biopsychological human organism and the persons, objects, and symbols in its immediate external environment. To be effective, the interaction must occur on a fairly regular basis over extended periods of time. Such enduring forms of interaction in the immediate environment are referred to as proximal processes. (Bronfenbrenner & Morris, 2006, p. 797)

Proximal processes are at the forefront of bioecological theory because they serve as the conduit for synergistic interrelations between the characteristics of the person and their environments across time. Operationally, as part of the PPCT model, proximal processes can be systematically investigated as a function of person characteristics, context, and time. Bronfenbrenner almost exclusively wrote about proximal processes as being positive (i.e., leading to competence and buffering against disfunction), but Merçon-Vargas et al. (2020) delineated the term *inverse proximal processes* to describe "detrimental interactions in the immediate environment that take place over extended periods of time on a fairly regular basis, becoming increasingly complex" (p. 329). In this adaptation of ecological theory, we embrace this more expansive notion of proximal processes, as these two types of proximal processes offer a more realistic framework for understanding youth and their families. However, as iterated previously, competence and dysfunction are culturally defined constructs; what is deemed a successful developmental outcome varies by culture and sub-culture. Similarly, whether a proximal process is positive or inverse is defined by the cultural group of the developing child or adolescent.

The unique features of virtual microsystems impact the forms proximal processes take within them. The third modification of our neo-ecological theory states: *The opening and closing of virtual microsystems is defined by the interactions and activities in which the developing individual engages.* More simply, digital interactions and activities define the existence of the virtual microsystem.

And yet, not all interactions taking place in virtual microsystems are proximal processes; digital platforms are simply another place in which we live, work, and play (e.g., watching TikTok videos, checking the weather, online shopping). These activities are not (typically) proximal processes because they are not usually reciprocal and do not increase in complexity over time. In the physical world, examples of these everyday interactions and activities abound (e.g., eating breakfast, taking a shower, having a cigarette break, riding on the bus, or driving to work). However, physical microsystems continue to exist, even when proximal processes are not occurring within them. By contrast, virtual microsystems arise and are sustained by interactions and activities, *some* of which are proximal processes.

Bronfenbrenner originally conceived of two forms of proximal processes: (a) those with other persons and (b) those with objects and symbols. As objects and symbols have technologized significantly since the original delineation of proximal processes, we propose modification four:

4. *Proximal processes can take three forms: symbolic, relational, and complex.*

   a. *Symbolic* proximal processes are reciprocal, increasingly complex interactions between the developing individual and *objects and/or symbols* within a microsystem over extended periods on a regular basis.
   b. *Relational* proximal processes are reciprocal, increasingly complex interactions between the developing individual and *persons* within a microsystem over extended periods on a regular basis.
   c. *Complex* proximal processes are reciprocal, increasingly complex interactions between the developing individual and *both persons and objects and/or symbols* within a microsystem over extended periods on a regular basis.

This modification is necessary to describe the forms of proximal processes that can occur within virtual and physical microsystems. Obviously, all three forms take place regularly in physical microsystems. For example, within a home microsystem a child may read books of increasing complexity on a regular basis (symbolic), engage frequently

in racial socialization practices with their father (relational), and play chess every week with their grandmother (complex). In virtual microsystems, only relational and complex proximal processes can occur. Symbolic proximal processes, even if they utilize technology, will always take place within the physical microsystem of the developing individual. For example, imagine a child at home creating and playing in a solo Minecraft world. While Minecraft is linked to an online server that modifies game conditions in response to the child's actions, this activity parallels other proximal processes possible in the child's home microsystem, like building with Lego, laying out train tracks, or playing a video game unconnected to the internet. All of these objects and symbols invite "attention, exploration, manipulation, elaboration, and imagination" (Bronfenbrenner & Morris, 2006, p. 798) without interaction with other persons. In a study of Scottish pre-school children, Arnott (2016) found that the children interacted with tablets as they did other objects and symbols in the classroom. Whereas adults view technology as being distinct from other play, children see technological tools as an inherent part of their worlds.

Relational and complex proximal processes in virtual microsystems reflect the unique features inherent in these co-constructed contexts. Although some virtual microsystems may be relational (i.e., mostly Web 1.0 platforms like video chatting, text messaging, email), the most pertinent to child and adolescent development are complex proximal processes, mostly occurring on Web 2.0 platforms (e.g., social media platforms, online multiplayer games). Granic and her colleagues (2020) discussed numerous interpersonal and intrapersonal processes that can occur online during adolescence. Even though Granic et al. did not describe these processes as proximal processes (nor them occurring within virtual microsystems), we believe that their paper provides an excellent starting point for scholars interested in examining positive proximal processes happening in virtual microsystems.

Positive proximal processes

According to Granic et al. (2020), adolescents are finding communion with their peers in virtual microsystems. By making social connections with like-minded persons on social media platforms and online games, adolescents can find socioemotional support and strengthen their mental health. Opportunities for such proximal processes are not monolithic, and positive outcomes are the results of an interrelation of person characteristics and the online environment. In addition, virtual microsystems offer opportunities for proximal processes that promote the development of agency and independence. For example, the Hero's journey, a common genre of online games, can help build confidence through overcoming obstacles and developing resiliency to

failure (Granic et al., 2020). Some online games (e.g., Fortnite) are also designed to dynamically adjust to the skill level of the player, helping to ensure that the game play is meeting and pushing the developmental needs of the player (Navarro, 2021). Granic and colleagues also provided illustrative examples of numerous games that encourage the development of positive coping strategies. Social media platforms provide opportunities for storytelling and sharing of narrative identity with peers, which can play an important role in developing self-esteem and developing social skills. Granic et al. (2020) wrote: "Trusted and supportive peers who can bear narrative contradictions are essential for young people to eventually settle on narrative identities that feel authentic, honest, and generative" (p. 207). Further, for adolescents who may feel marginalized or isolated (e.g., LGBTQ youth, youth of color) in their physical microsystems, virtual microsystems offer opportunities for connections with like-minded individuals and socioemotional support (Odgers & Jensen, 2020).

Inverse Proximal Processes

Research suggesting deleterious impacts of inverse proximal processes in virtual microsystems is copious. Although some of these effects are likely overblown (or erroneous), the unique features of virtual microsystems present a multitude of opportunities for adolescents to engage in proximal processes that can lead to dysfunction. The publicness, permanence, availability, visualness, and cue absence of digital contexts allow for unique opportunities to bully and intimidate others (Nesi et al., 2018b). The availability of social media means that bullying and victimization is no longer temporally or spatially bound; bullies can reach their victims at any time, day or night, and microsystems that were safe in previous generations (i.e., home) no longer offer respite. Further, because cyber victimization is happening in virtual microsystems, it may be less visible to parents and teachers. The *moral panic* about technology (at the macrosystemic level) may influence some parents to respond harshly or punitively to cyber victimization, and consequently, some youth may be less likely to report being cyber victimized. The publicness and permanence of virtual microsystems may compound the fear and humiliation victims feel because it can be witnessed by many people over and over, extending the duration and frequency (i.e., meso-temporal impact) of the inverse proximal processes. The mesosystemic links between the virtual and physical microsystems (e.g., school) may lead to further deleterious outcomes and also raises concerns related to jurisdictional responsibility.

In addition to cyber victimization, the unique features of virtual microsystems may encourage inverse proximal processes, like social comparison, that can lead to feelings of insecurity and anxiety, body image concerns, and disordered eating (Holland & Tiggemann, 2016). The accessibility, asychnronicity, and visualness of social media platforms (e.g., Instagram) are conducive to comparisons; adolescents can effortlessly access millions of images, many of which have been carefully staged and edited to look perfect (i.e., carefully curated demand characteristics). Prevailing cultural beliefs about beauty (i.e., macrosystemic influence) are internalized, and can intensify inverse proximal process. From a micro-temporal and meso-temporal perspective, the intensity, duration, and frequency of these inverse proximal processes can lead to poorer body image and increased disordered eating (Holland & Tiggemann, 2016).

Synergy

In the sections above, we explored neo-ecological theory through each component of Bronfenbrenner's Process-Person-Context-Time model (albeit in a different order). For heuristic purposes we explored these elements separately, but development is the result of the multidirectional interrelations, or synergy, between these constituent elements. Person characteristics, context, and time are interdependent; all three forces synergistically shape "…the form, power, content, and direction of the proximal process" (Bronfenbrenner & Morris, 2006, p. 798), which in turn influence elements of the person, context, and time. As such, operationalizing neo-ecological theory requires scholars to embrace longitudinal designs, and to gather data not only about people and their environments, but also about the interactions and activities going on within them. Instead of studying each of these elements in isolation, "it is best to eschew main effect explanations in lieu of the complex interplay of internal and external forces reciprocally influencing each other at every moment" (Hollenstein & Colasante, 2020, p. 255).

Applying Neo-ecological Theory

As we have discussed at length in our previous publications (e.g., Navarro et al., under review; Tudge et al., 2009, 2016), most applications of Bronfenbrenner's bioecological theory and corresponding PPCT research model have struggled to operationalize his ideas with fidelity. This is likely due to a multitude of factors, including that many scholars use earlier iterations of Bronfenbrenner's theory, the proliferation of the notion that bioecological theory is solely related to context (e.g., textbook diagrams depicting nested rings of context), and the fact that Bronfenbrenner did not undertake research using his model and rather used the work of other scholars to illustrate his ideas. Combined with the sheer expansivity of the theory, scholars may feel overwhelmed when trying to apply Bronfenbrenner's ideas in their own research and teaching. After reading this paper, delineating an adaptation of his

model with even more complexity, applying neo-ecological theory to your research or teaching may seem daunting.

To avoid this dilemma, we recommend applying and teaching neo-ecological theory in a simple and stepwise fashion, using the Process-Person-Context-Time model as a guide (see Navarro et al., under review, for more detail). This is outlined briefly below, utilizing a fabricated research question (*How might the type of digital interactions in which youth engage impact their substance use?*) and corresponding research and teaching examples. At a *minimum*, a study utilizing neo-ecological theory should address the following four requirements:

1. *Proximal Processes.* The selected proximal process should be an interaction or activity that is increasingly complex (positive or deleterious), reciprocal between the focal individual and other person(s)/object(s), and occurs regularly for an extended period. The selected process should be measured at a time point between baseline and when the outcome is measured.

   a. *Research example:* Utilizing a survey measure, youth reported on the interactions in which they typically engaged in on their most frequently used social media platforms. This information was utilized to determine if they predominantly engaged in active (i.e., commenting/liking friends' posts, posting content themselves) or passive (i.e., scrolling but not commenting, liking, or posting) interactions online.

   b. *Teaching example:* Ask students to brainstorm the different types of interactions and activities taking place in virtual microsystems that they think might relate to substance use. Probe into why they think these activities might relate to the outcome, and if these interactions and activities constitute proximal processes in terms of complexity, reciprocity, and regularity.

2. *Person Characteristics.* Person characteristics feature twice—as both an antecedent and an outcome. The antecedent variable should be measured (or analyzed) categorically, with a minimum of two levels, and selected for its empirical and theoretical relevance. The outcome variable should be measured after the proximal process has taken place.

   a. *Research example:* In a baseline survey, youth reported on their propensity to compare themselves to others online (i.e., social comparison orientation (SCO)). After separating the sample into terciles based on this measure, the top and bottom terciles comprised the person characteristic in two-levels: high propensity for SCO and low propensity for SCO. Externalizing behaviors, as reported at the third time point, served as the outcome variable.

   b. *Teaching example:* Ask students to generate a list of possible person characteristics that they think may influence the chosen proximal process selected earlier. Urge students to think about person characteristics beyond the focal child/adolescent, like parents or caregivers, siblings, and peers. Also ask student to generate a list of possible ways of measuring substance use for the outcome variable.

3. *Context.* At a minimum, only *one* level of context need be included in the study design. Like person characteristics, the chosen contextual influence must also be operationalized categorically with two levels.

   a. *Research example (only* one *need be addressed):*

      i. *Microsystem:* At baseline, participants submitted screenshots of their time spent on digital media platforms over the course of the preceding week. Based on this information and coding scheme, youth were assigned to one of two virtual microsystems: (a) high visualness and (b) low visualness.

      ii. *Macrosystem:* At baseline, participants reported on their parents' occupation and income and were assigned to one of three socioeconomic groups (i.e., high, middle, low).

   b. *Teaching example:* One level of context at a time, ask students to think through contextual influences at the microsystem, mesosystem, exosystem, and macrosystem. How might features of the home microsystem influence the active or passive nature of youth's interactions online? How might unique features of virtual microsystems influence these interactions? What about home-school relations (i.e., mesosystem)? How might decisions made by software developers (i.e., exosystem) influence these interactions? What about socioeconomic status or systemic inequalities (i.e., macrosystem)?

4. *Time.* A longitudinal study design is necessary to examine the influence of proximal processes over time. In addition, macrotemporal influences must also be considered.

   a. *Research example:* Data for the study was collected at three time points: (a) baseline at which antecedent person characteristics and contextual influences were measured (e.g., SCO, externalizing behaviors, platform visualness, socioeconomic status), a

second time point when proximal processes were measured (e.g., social media interactions), and a final time point when the outcome was measured (e.g., externalizing behaviors adjusted for externalizing behaviors at baseline).

b. *Teaching example:* Ask students to think about how the selected person characteristics, contextual influences, and proximal process may interact with each other over time. Brainstorm how the proximal process may mediate relations between a social comparison orientation and substance abuse among adolescents. Finally, ask students to consider the temporal conditions. How might recent events or cultural change influence the proximal process, person characteristics, and contextual influences?

While this example places interactions occurring virtual microsystem at the forefront, the theory can also be applied to research where digital technology may be not be as central. In today's technologized world, there are likely very few phenomena in which digital technology is not an influence in some way.

Conclusion

Bronfenbrenner's ecological (and later, bioecological) model of human development has been a backbone of developmental science since its inception in the 1970s and offered an overarching theoretical framework for understanding the multitude of influences on development across time. However, as it was written in the 20th century, Bronfenbrenner's bioecological model requires significant modifications to reflect the virtual and technological contexts in which we currently communicate, learn, play, and work. In delineating neo-ecological theory, we hold true to the tenets of bioecological theory, but suggest key modifications to reflect our changed world. We delineated a fundamental modification of the microsystem, namely the existence of two forms of microsystems—physical and virtual. In addition, at odds with bioecological theory, we emphasized the role of the macrosystem (i.e., the influences of culture and within-society subcultural variation) in understanding development. These seismic changes ripple across the PPCT model, opening new avenues of inquiry into development in the digital age. For example, future research should explore mesosystemic relations across physical and virtual microsystems, and the varied functions and features of different types of virtual microsystems within the PPCT model.

In our technologized world, virtual microsystems are central contexts in the lives of youth, and are thus critically important to researchers, practitioners, and policy makers.

In addition, without research incorporating the influences of proximal processes in virtual microsystems, software developers will be in the dark about how best to design their platforms to promote positive outcomes for adolescents, and families. Further, we believe that all scholars studying children, youth, and families, regardless of their specific field on inquiry, should consider the ways digital contexts may influence their outcomes of interest.

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