How Adolescents Learn to Build Social Bonds: A Developmental Computational Account of

Social Explore-Exploit Decision Making

Kathy T. Do*, Sophie G. Paolizzi, & Michael N. Hallquist

Department of Psychology and Neuroscience, University of North Carolina Chapel Hill

235 E. Cameron Avenue Chapel Hill, NC 27599-3270 United States

*Corresponding Author:
Kathy T. Do
235 E. Cameron Avenue
Chapel Hill, NC 27599-3270
kathydo@unc.edu

Abstract

Building social bonds is a critical task of adolescence that affords opportunities for learning, identity formation, and social support. Failing to develop close relationships in adolescence hinders adult interpersonal functioning and contributes to problems such as loneliness and depression. During adolescence, increased reward sensitivity and greater social flexibility both contribute to healthy social development, yet we lack a clear theory of how these processes interact to support social functioning. Here, we propose synthesizing these two literatures using a computational reinforcement learning framework that recasts how adolescents pursue and learn from social rewards as a social explore-exploit problem. To become socially skilled, adolescents must balance both their efforts to form individual bonds within specific groups and manage memberships across multiple groups to maximize access to social resources. We draw on insights from sociological studies on social capital in collective networks and neurocognitive research on foraging and cooperation to describe the social explore-exploit dilemma faced by adolescents navigating a modern world with increasing access to diverse resources and group memberships. Our account provides important new directions for examining the dynamics of adolescent behavior in social groups and understanding how social value computations can support positive relationships into adulthood.

Keywords: adolescence; exploration; reinforcement learning; social reward; peer groups

Imagine Taylor, a high school freshman, navigating the complex dynamics of a social network. While Taylor's main goal is drumming in a rock band, they also value other social goals, like gaining popularity and maintaining close friendships. Joining a social group with like-minded peers (e.g., local rock band) provides opportunities for Taylor to enhance their drumming skills—a valuable resource for their future music career. Once in the band, Taylor might preferentially form social bonds with knowledgeable band members to improve their own drumming skills and achieve the collective goal of going on tour. Yet, Taylor also needs to balance memberships across clubs and friend groups offering other valuable resources, such as popularity or social support. Focusing solely on drumming might cause Taylor to miss opportunities to connect with other groups offering different resources, which might be critical if the band breaks up or Taylor's interests change in the future.

A fundamental task of adolescence is achieving **mature social competence** (Table 1), or developing the knowledge and skills to be capable of functioning independently from adults. The vignette above illustrates one example of how building social bonds within and between peer groups in adolescence afford valuable opportunities for supporting mature social competence. Belonging to a social group provides avenues for building individual bonds and benefitting from the tangible **social resources** they provide (Table 1), such as social support, acquisition of specialized skills, and elevation of group status (Kindschi et al., 2019; Kreager et al., 2011). Adolescents who adapt well to the demands of evolving relationships and group memberships have better health outcomes in adulthood (Almquist, 2009; Van Harmelen et al., 2017), whereas adolescents who struggle with building status and support networks are vulnerable to later psychosocial and mental health challenges (Blakemore & Mills, 2014; Seok & Doom, 2022).

Learning about and adapting to these complex and dynamic social experiences may be driven by the development of neural circuits that underlie **social flexibility** and **reward sensitivity** (Table 1). During adolescence, heightened activation in brain circuits associated with social-affective processing can facilitate flexible action selection and execution of goal-directed behavior in motivated contexts (Blakemore & Mills, 2014; Crone & Dahl, 2012; Foulkes & Blakemore, 2016), such as in pursuit of social status goals (Capella et al., 2023; Do et al., 2020). In addition to greater social flexibility, adolescents relative to adults exhibit heightened activation in brain circuits associated with reward processing, especially in peer contexts, perhaps facilitating adaptive learning from rewards and exploration of peer environments that bring new information (Chein et al., 2011; Davidow et al., 2016; DePasque & Galván, 2017; Lloyd et al., 2021). Although greater social flexibility and increased reward sensitivity both support healthy social development in adolescence, we lack a clear theory of how these co-occurring neurodevelopmental processes interact to support social functioning.

Computational accounts, grounded in learning theory and developmental cognitive neuroscience, can address this gap by specifying mathematical predictions about the learning and decision processes involved in forming and maintaining social bonds in adolescence. Here, we propose a developmental computational framework of social explore-exploit (SEE) decision-making, which suggests these two neurodevelopmental processes interact to help adolescents learn the subjective value of bonds and engage in flexible social behaviors to achieve mature social competence. Specifically, heightened social flexibility in adolescence may facilitate the formation and maintenance of individual bonds (e.g., with peers or romantic partners). However, dyadic bonds are typically embedded in richly interconnected social groups that provide valuable resources that support mature social competence (e.g., advanced drumming skills for music

career). Heightened reward processing may help an adolescent estimate not only the subjective value of membership in a peer group, but also the value of bonding with a specific person within the group and the resources embedded in those bonds. Moreover, building strong social bonds with groups and individuals within those groups requires time and effort. Thus, sensitivity to social signals that predict rewards both within and across groups becomes vital for supporting social interactions that lead to positive outcomes associated with adult social functioning.

Before expanding on our formal account, we review key insights from sociological studies on the **social capital** (Table 1) embedded in collective networks and neurocognitive research on foraging and cooperation dynamics. These literatures lay the groundwork for our theory, which aims to formalize how the dynamics of relationship formation and group membership in adolescence depend on two key factors: 1) estimating the subjective value of bonds with individuals and groups (reward sensitivity); and 2) adjusting future interactions to preferentially strengthen bonds that collectively provide valued resources (social flexibility). We then articulate a developmental computational account of social explore-exploit decision-making using two formal value-based models of **explore-exploit decision-making**: **reinforcement learning** (RL) (Sutton & Barto, 2018) and the **Marginal Value Theorem** (MVT) (Charnov, 1976) (Table 1). We unfold how a decision rule (i.e., policy) incorporating principles of both helps to resolve two key social goals during adolescence that are subject to explore-exploit decision-making: 1) managing individual bonds within groups, and 2) balancing memberships across multiple social groups. We also consider individual differences in several psychosocial factors (e.g., personality) that may change adolescents' approach to resolving the social explore-exploit decision dilemma. Finally, we provide a roadmap for testing our predictions and

alternative models explaining how adolescents build social bonds within and across groups, with implications for long-term psychosocial adjustment.

Building Valuable Bonds for Social Capital and Resources

Personality and interpersonal theories of motivation suggest that social goals can be organized along two axes, agency and communion, that exist on an **interpersonal circumplex** (Fournier et al., 2010). Agentic goals usually relate to one's ability to distinguish oneself or attain high social status, popularity, and dominance (Hopwood et al., 2021). Communal goals on the other hand relate to attaining affiliation, social closeness and cooperation (Wiggins, 1991). Regardless of their own goals, individuals typically act within collective networks, aligning themselves with several groups (e.g., clubs, peer groups) as the basis of their social identity (Dunphy, 1963) and developing shared preferences and goals with others. These networks promote a mutual understanding of the world that reinforces group belongingness (Delgado et al., 2023). Indeed, strong community bonds predict greater economic mobility (Chetty et al., 2022a), community resilience (Aldrich & Meyer, 2015) and positive health and psychological outcomes (Ehsan et al., 2019) for individuals embedded in those networks. Similarly, maintaining a desired status position within one's social groups confers advantages across species. For example, in baboons, societal structures predict lower stress levels for specific ranks (Sapolsky, 2005), suggesting desired positions in social networks provide fitness advantages.

Despite the potential benefits of social bonds and status for psychosocial functioning, the mechanisms by which bonds promote access to valued resources within a group remain poorly understood. Social bonds and networks—and the norms of reciprocity and trustworthiness that arise from them—are central in theories of social capital (N. Lin, 2007; Putnam, 2001) (Table 1). Leading theories have suggested social capital encompasses the bonds between individuals

(Glanville & Bienenstock, 2009), the resources generated by group membership (Bourdieu & Wacquant, 1992), and the act of investing in the bonds (N. Lin, 2007). Interdisciplinary research on social capital across micro (e.g., individual) as well as a macro (e.g., societal or structural) levels more consistently emphasize that social networks function as environments or "patches" that individuals must access to benefit from group resources (S.-W. Lin & Lo, 2015).

Theories of social capital help us understand that bonds are related to the value of social interaction, but are less clear on the currency that motivates individuals to invest in social networks. In our value-driven framework, we propose that social bonds might be an integrated value representation of all the resources afforded by social group "patches" or individual relationships. Importantly, we emphasize that both status and affiliation resources can motivate strengthening bonds to form a cohesive network, but some social opportunities must be foregone to gain others. For example, while Taylor's investment in affiliation resources like close friendships might provide emotional support during personal crises, having a reputation as a good drummer may elevate their social status and aid in achieving agentic goals.

A formal framework like SEE aims to describe how individuals make decisions in social contexts based on their beliefs about what is valued, but is agnostic to whether those decisions are driven by affiliative, emotional connections or more status-driven goals aimed at obtaining specific resources. The assumption that *value* guides social explore-exploit decision-making is critical, as individual preferences for social resources are heavily influenced by factors such as resource availability, personality and interests, and cultural norms (Coleman, 1988; Hommerich & Tiefenbach, 2018; Putnam, 2001). Consider, for example, the differences between individualistic versus collectivistic cultures. In a society valuing individual success, social exploration for Taylor might involve optimizing relationships to gain status-related resources

like invitations to important parties. However, in more collectivistic cultures, Taylor might

prioritize affiliative opportunities by investing time in strengthening community or extended

family relationships. In research that takes a resource view of "ethnic" social capital, these

differences indeed emerge (Goza & Ryabov, 2009; Pearrow et al., 2019). Additionally, social

explore-exploit decision-making likely includes a mixture of conscious influences ("I should

prioritize work over visiting my family") and subconscious influences (e.g., reflexively calling

out of work for a family emergency) that inform the value of various social bonds across groups

and the resources embedded in them.

How Social Bond Dynamics Relate to Explore-Exploit Decision-Making

Individuals are often motivated to interact with group members in mutually beneficial

ways, fostering social closeness and reducing social distance. Previous research finds that

learning in social contexts depends on corticostriatal circuitry that encodes the value of

rewarding outcomes during social interactions (Fareri et al., 2012, 2015; Martins et al., 2021)

and a separate circuit implicated in stress and emotion regulation that encodes aversive outcomes

such as social rejection (Muscatell et al., 2022). The formation and maintenance of social bonds

is therefore driven by reinforcement at a basic level, by keeping account of social experiences

from past interactions with specific individuals and groups to make predictions about others and

adjust investment in different relationships (Delgado et al., 2023; Vanyukov et al., 2019). Here,

we propose that increased reward sensitivity and greater social flexibility during adolescence

may attune adolescents to a *social explore-exploit (SEE) decision-making dilemma*: How does

one balance seeking new social experiences and information (exploration) versus choosing

actions likely to be rewarding based on past social interactions (exploitation)? By joining friends

for board games again, Taylor may miss out on auditions for battle of the bands, where they

could potentially form new, higher value bonds with local performers. *Exploration* can be costly because options with unknown outcomes can lead to unfavorable outcomes, while *exploitation* can be costly if familiar actions lead one to overlook better alternatives or miss opportunities afforded by new environments. To resolve this social explore-exploit dilemma, adolescents should learn to maximize desired social resources by choosing how much to interact with different individuals and groups. They consider not only the immediate rewards available from such interactions, but also the distal social benefits. Over time, adolescents accumulate information about which individuals and groups are likely to confer benefits aligned with their diverse goals, helping them form advantageous social bonds.

Adaptive exploration in social environments involves the tracking and pursuit of resources afforded by each group and the individuals within them. An adolescent needs to discover which groups provide high value social resources, balancing opportunity and effort costs when arbitrating between groups (Constantino & Daw, 2015). Like foraging for food across different environments, adolescents encounter many social group "patches" that each afford unique advantages. In the SEE dilemma, adolescents need to identify and maintain the most beneficial group memberships and individual bonds for successful social functioning. Changes in the social environment are responsive to one's actions, such as losing access to a mutual friend group after a romantic relationship ends. Thus, forming beneficial bonds within and across multiple social groups in adolescence is an interpersonal, transactional process that dynamically changes over time based on past interactions with group members.

When deciding whether to form new bonds, social explore-exploit decision-making may involve consideration of the expected value of different forms of social capital (e.g., when lonely, experiences of social closeness may be of greater value than social status) and the

distribution of capital within specific relationships and groups. To resolve the SEE dilemma, we argue that adolescents seek to maximize the expected rewards derived from bonds among individuals and across groups (herein referred to as **social value**) (Table 1). The social value of each group or individual can be learned directly from social experiences that reveal the unique resources embedded in those bonds, or indirectly through social transmission like gossip or reputation (Emler, 1994; Jolly & Chang, 2021). Rumors about a student musician group discussing a record deal could motivate Taylor, who is interested in musical resources, to attend their next show. We distinguish social value from resources in that social value is an estimation of the value of social bonds, whereas resources function akin to tangible rewards (Table 1). For example, Taylor may place a high *social value* on impressing the top band's lead singer because the resulting bond would confer access to tangible *resources* like a spot in the band. Moreover, the types of social resources pursued by adolescents helps define their roles within peer groups, shaping their identity development (Ragelienė, 2016). As adolescents seek group membership, signaling group-consistent preferences and goals is crucial to maximize access to desired group resources. When an adolescent's interests align well with a group, their initial interactions with group members can increase the likelihood of acceptance, creating a positive feedback loop between their actions and the social value returned on their investment.

Social Structures in Humans

Because social value comes in multiple forms, adolescents may vary in their preferences for one form over another, and groups may differ in how open or exclusive they are. Thus, an adolescent's policy for investing in relationships that maximize social value within and across groups must account for these structural complexities. Peer groups can overlap and have hierarchical structures (Cairns et al., 1985; Dunphy, 1963), like a small group of friends within a

larger social group such as a homeroom. Individuals also have multiple group identities simultaneously, for example as a function of both gender identity and age group (Kang & Bodenhausen, 2015). With multiple social identities comes the prioritization of group membership based on the resources each group affords, facilitating access to a broader range of social resources within their network (Iyer et al., 2009). Just as a varied diet is important for survival to many foragers, membership in multiple high-value social groups that afford different resources can predict higher subjective well-being (Jetten et al., 2015). However, in line with classic explore-exploit tensions related to effort and opportunity costs, these benefits do not always outweigh the costs of simultaneously investing in too many groups (Sønderlund et al., 2017). Often, joining a high-value group that provides key resources requires considerable effort investment in forming and maintaining bonds with its members. Thus, adolescents need to decide which groups in their environment are worth investing in to maximize desired rewards.

Variation in bond strength leads to some groups with more abstract definitions and looser membership investment. While one may have tighter cohesion with groups providing social resources central to their identity, even distal bonds or "weak ties" reflect potential caches of social value (Granovetter, 1973). For example, fans of a popular band who have never previously interacted can instantly bond at a concert, transcending age, gender, and social class (Black, 2005; Wann et al., 2011). This is relatively uncommon in other species, where social groups are typically based on immutable characteristics like age or sex, or geographical or familial foundations (Clutton-Brock, 2021). Like primates, human society is multi-level in nature and includes not only low-level individual connections (e.g., between families), but also bonds and hierarchies between group members with little to no individual familiarity (Koski et al., 2015).

Thus, it strategic to not only develop a strategy for estimating the resources available in one's

local groups and bonds, but also compare local groups to other potential sources of social value.

The Value of Social Value

In addition to the social resources and rewards that groups provide, another major

advantage is that groups can work collaboratively to maximize rewards and share information

about the environment. Working collaboratively allows organisms to overcome their individual

constraints by adopting diverse foraging strategies across the group that support both exploiting

known options and exploring new, potentially better ones (Giraldeau & Dubois, 2008). For

example, one member of Taylor's music friend group might comb through David Bowie's full

discography in search of interesting, lesser known songs even as another person samples widely

from new releases on music streaming services (Goldstone & Gureckis, 2009; West et al., 2011).

To make these systems work, individuals are motivated by social value to stay involved in

networks where they can minimize individual efforts and instead exploit the experience and

knowledge of others to direct efficient exploration.

By being part of a group, adolescents gain valuable knowledge about social norms. The

more bonds they form, the more they learn about appropriate behavior, navigating interpersonal

conflicts, and maintaining relationships. Repeated interactions with people from different groups

allows individuals to learn how proper and improper social behavior vary across time and

contexts (Rojek-Giffin et al., 2023). Individuals usually identify others in their environment who

possess desirable resources, and then observe and imitate their behaviors (Heyes, 2016). In

naturalistic foraging, using information provided by others' experience speeds up exploration by

signaling which patches confer valuable resources, reducing unproductive exploration (Smolla et

al., 2015). This basic social learning is conserved across species (Heyes, 2012), with the primary

advantage being a massive reduction in individual costs such as exposure to predation, time, and

effort (Ruel et al., 2021). Because other individuals frequently demonstrate the highest value

behavior, winning strategies nearly always include some use of social information (Rendell et al.,

2010). For example, the "wisdom of the crowds" phenomenon (Mannes et al., 2014) highlights

that a diverse group can collectively solve problems more accurately than its most expert

individuals alone (Surowiecki, 2005). It also holds true in adolescent social contexts, where peers

tend to increase the value of less certain options (Chein et al., 2011; Somerville et al., 2019). The

adolescent's exposure to different social norms and values depends on the social groups they

choose to invest in. This collectively learned social information facilitates successful social

interactions, enables the adjustment of social behaviors across socio-temporal space, and helps

sustain bonds with desired groups (van Dijk & De Dreu, 2021).

Why Maximize Social Value in Adolescence?

We emphasize adolescence as a key developmental period for maximizing social value in

social interactions across groups for three reasons. First, continued caregiving by parents and

extended family members typically addresses basic dietary and security needs during the

transition to adolescence (Hrdy, 2011), enabling youth to concentrate on developing social skills

and exploring advantageous groups that support the transition to adult social roles and

responsibilities. Second, unstructured play and exploration with peer groups helps to expand and

refine the behavioral repertoire of the adolescent. Adolescents naturally seek new connections,

helping them learn the requisite skills and knowledge that can be advantageous in adulthood

(e.g., conflict resolution skills in friendships) (Hartup, 1992), as well as achieve mature social

competence (e.g., specialized roles) and fitness (e.g., mate selection). Third, puberty supports a

period of extended social exploration and behavioral plasticity. However, early life stress can

shorten this period of plasticity of exploration and learning (Smith & Pollak, 2021; Xu et al., 2023), undermining important developmental needs (e.g., formation of close friendships) and increasing physical and mental health risks (Sciberas & Fournier, 2023). Early life adversity tends to tip the balance away from exploration toward prematurely exploiting a narrower range of skills and knowledge that serve immediate survival challenges (Frankenhuis & Gopnik, 2023), such as babysitting siblings while parents work instead of going to a classmate's party. In sum, understanding how adolescents adaptively engage in social exploration and develop key social skills can inform efforts to support long-term health and psychosocial functioning (see (Frankenhuis & Gopnik, 2023; Gopnik, 2020) for more thorough treatments of this topic).

A Developmental Computational Account of Social Explore-Exploit Decision-Making

Building social bonds during adolescence is crucial for accessing the various resources embedded within those relationships and social structures. We extend two formal models of value-based learning and decision-making to adolescent social behavior, articulating specific hypotheses about how social value influences individual bonds within groups and how value can guide flexible relationship investment across multiple groups (Table 2). Specifically, whereas the RL framework is well-suited for formalizing how social value shapes individual bond formation within a group (*within-group sampling and optimization period*), the MVT framework informs an understanding of when one should leave a group to explore others (*between-group switches period*). Before discussing the empirical groundwork and predictions of our model, we first provide an overview explaining how social bond dynamics within and between groups are understood within the complementary RL and MVT frameworks. Importantly, our developmental computational account is a first attempt to translate verbal psychological models of adolescent social behavior in groups using value-based decision-making models of explore-

exploit behavior. However, we recognize that as stated, the mathematical formalisms of our theory do not provide a single computational model that could be tested through computational and behavioral experiments (see *Extensions and Limitations of SEE Framework* section below). Rather, we hope that this comprehensive approach to formalizing predictions about how social explore-exploit dilemmas may be resolved in adolescence provide key components of future modeling and experimental efforts to understand social decision-making in adolescence.

Overview of Within-Group Bond Valuation and Between-Group Switches

How Does an Adolescent Learn the Social Value of a Group? Similar to naturalistic foraging, we conceptualize social groups as "patches" within social networks where multiple resource-providing individuals reside (Gabay & Apps, 2021; Hayden et al., 2011). Adolescents must form an estimate of the social values of these groups that guides decisions to become a member of a given group. We hypothesize that the social value of a given group g, V_g (i.e., group valuation), is defined as the sum of the social value estimates for each person in the group, V_j, multiplied by their estimated investment in the group, o_{jg}:

$$V_g = \sum_j V_j \, o_{jg} \tag{1}$$

where $0 < o_{jg} < 1$ and a larger o_{jg} indicates a highly invested member of the group. Early in learning, group valuation does not depend on membership, as prior signals (e.g., reputation) or individual preferences (e.g., preference for music over sports) can shape the estimated social value of a group before entry attempts.

How Does an Adolescent Learn the Social Value of a Person Within a Group? Like RL agents maximizing desired rewards and avoiding punishments, our account suggests that adolescents track the social value of each group member by learning from the outcomes of social

interactions in terms of the resources they afford. During *within-group reward sampling*,

adolescents use their social experiences to update the expected resources for each group member

and combine these estimates to inform the overall expectation of group value. We define the

social value of each group member, V_j (i.e., individual valuation), as the sum of the k resources

they provide (e.g., music knowledge), weighted by the adolescent's preference for specific

resources (P_k; e.g., preference for music over sports):

$$V_j = \sum_k V_{jk} P_k \qquad (2)$$

It is an open question whether the value of social bonds reflects a single integrated

currency that blends an individual's preferences for different resources with the distribution of

resources available within a given relationship (Warren et al., 2011). For example, how does

Taylor who prefers music over sports weigh the opportunity to bond with a low-status bandmate

against the high-status star of the school play?

How Does an Adolescent Update their Social Value Estimate of a Group Member

Based on Social Experience? We propose that adolescents follow a form of delta rule learning

to update the social value of a group member j following each interaction t based on the k

resources that reinforce or weaken the individual bond:

$$V_{jk}(t + 1) = V_{jk}(t) + \alpha[r_k - V_{jk}(t)] \qquad (3)$$

where r_k is the resource-related reward, $[r_k - V_{jk}(t)]$ is the discrepancy between

expected and obtained resource outcomes (i.e., **prediction error** (PE); Table 1) in the current

interaction. The learning rate (α) reflects the extent to which social feedback on each interaction

with group member j updates estimates of individual valuation (where $0 < \alpha < 1$). Repeated

resource-relevant experiences with the same group member can lead to updated estimates of

individual valuation. Crucially, learning from positive and negative experiences with individual

members often shifts the group's social value (Equation 1).

How Does an Adolescent Decide with Whom to Interact across Multiple Groups?

We propose that adolescents optimize within-group rewards by choosing whether to interact with

a given person j who is a member of group g in proportion to the valuation of all other group

members, V_m:

$$p(j \in g) = \frac{e^{V_{j \in g}}/\beta}{\sum_{m \in g} e^{V_m}/\beta} \tag{4}$$

where the temperature (β) captures the adolescent's tendency to explore unknown bonds

with others that could be better or worse (i.e., high β is associated with stochastic choices)

relative to exploit familiar bonds of highest value (low β prioritizes value-driven choices). This

perspective assumes that an adolescent has already decided to interact with members of a given

group, then selects an individual within the group. How might an adolescent decide whether to

interact with a given group g? Akin to within-group reward learning, decisions among groups

$p(g)$ may follow a similar softmax policy across group valuation estimates, V_{G_i}:

$$p(g) = \frac{e^{V_g}/\beta}{\sum_i e^{V_{G_i}}/\beta} \tag{5}$$

By extension, the probability of choosing to interact with any person across groups would

be the joint probability of selecting a group and a person within that group: $p(g)p(j \in g)$. An

alternative, and perhaps more compelling account, is that an adolescent chooses among all

possible individual bonds, influenced both by their valuation and by the overlap of others' group

memberships with one's own. That is, rather than decisions proceeding in two steps ("Which

group?", "Which person within the group?") as described in Equations 4-5 above, perhaps the

decision is "With whom should I interact given their relative value and their overlap in groups of

which I am a part?" The overlap in group membership between the adolescent and person j (i.e.,

homophily bias: g_j) constrains the adolescent's *choice* about with whom to interact. To decide

with whom to interact, the probability of choosing to interact with person j is defined by their

social value, V_j, compared to the value of all possible individuals with whom the adolescent

could interact, $V_M = \{ V_1, V_2, \dots, V_m \}$, the adolescent's tendency for stochastic exploration, β, and

overlap in group membership between person j and the adolescent, g_j:

$$p(j) = \frac{e^{V_j}/\beta}{\sum_m e^{V_m}/\beta} g_j \qquad (6)$$

How does an Adolescent Decide Whether to Stay in a Group or Invest in Other

Groups? Adolescents decide whether to stay with their current group or leave by comparing the

product between the group value estimate, V_g, and the local depletion rate, k (i.e., the rate at

which the group's value diminishes with time), to the expected social value afforded by the

broader environment (Gabay & Apps, 2021):

$$kV_g > ph \qquad (7)$$

where the overall rewards available in one's environment p, adjusted for opportunity cost

of time h (Charnov, 1976). That is, the local depletion rate k estimates how quickly the group's

resources decrease with each interaction (e.g., seeking support from a bandmate to the point they

begin to withdraw), thus scaling its overall value (but see *Modeling SEE Beyond Value* below).

With these basic ideas about within- and between-group learning dynamics in mind, how

do we account for the interplay among learning processes as adolescents resolve the social

explore-exploit dilemma? Here we consider how adolescents decide to join a social group, how

to maximize social value within the group, and how to decide whether to leave a group that may

not be as valuable as alternatives. First, to manage individual bonds, the adolescent initially

decides which group to join (*early group sampling*) based on its expected *group entry* costs and

resources (Figure 1A-B). The adolescent then relies on repeated interactions within the group to decide whether forming individual bonds affords valuable resources for gaining social capital (*within-group reward sampling and optimization,* Figure 1C). Second, to balance membership across multiple groups, the adolescent flexibly adjusts their investment among groups based on each group's social value (*between-group switches*; Figure 2A) and explores alternative groups when leaving offers greater benefits than staying (*restart early group sampling and entry*; Figure 2B). Below, we describe model predictions for each component of social explore-exploit decision-making, grounded in prior literature on relationship formation and maintenance and group entry and exit dynamics in adolescence. Importantly, although we present these within- and between-group components as if they flow linearly, these learning processes are likely operating in parallel (e.g., the adolescent may be considering leaving one peer group according to MVT even as they are optimizing connections in a different group according to RL).

Managing Individual Bonds: Within-Group Bond Valuation

Given that adolescents are members of multiple groups, how do they decide with whom to interact? One hypothesis proposes a two-step choice rule: first, choosing whether to interact with a group ("which group?", Equation 5) and then selecting a specific member *j* within a group *g* with whom to interact ("which person within the group?", Equation 4) in proportion to the valuation of all other group members. This strategy aims to optimize within-group rewards by joining preferred social groups and interacting with their members to learn their social value.

How Does an Adolescent Decide Which Social Group to Join? To learn what groups are worth foraging, we propose that adolescents initially estimate the social value of groups using observed signals (e.g., clothing or rumors), but not direct experience, that inform decisions to explore an unfamiliar group. Early in social foraging, adolescents may integrate prior

knowledge of available social resources with current signals of potentially valuable resources at

the dyadic and group level that alter their existing expectations about the resources provided by

bonding with an individual (V_j) or group (V_g). For example, knowledge of a peer's position in the

school network serves as a social prior on the value of affiliating with them (Schwyck et al.,

2023). If an adolescent knows their classmate is the lead in the school play, knowledge of others

in the drama club ($V_{g_{\text{drama}}}$; Figure 2A) might be used to form an estimate of the resources to be

gained by interacting with them (V_j, Figure 1C). Conversely, in situations where priors are less

informative, such as moving to a new school, an adolescent should engage in exploratory *early*

group sampling to build estimates of social value at both the individual and group levels.

In addition to priors on social value, one's preferences regarding different resources (e.g.,

music knowledge) can simplify social foraging problems by guiding adolescents toward groups

that are rich in preferred resources. Taylor's preference P_k for finding a band is strong, so they

may invest more effort in interacting with peers who signal interest in music (Figure 1A).

However, preferences are likely allocated across several resources. In addition to music

knowledge, a classmate's perceived attractiveness might increase their social value (e.g.,

indicating a potential romantic interest) and motivate an adolescent to explore a new social group

(Chetty et al., 2022b). In sum, prior knowledge and signals of preferred resources help

adolescents estimate available resources in their environment and identify high value group

"patches" that provide access to these resources. These initial maps of the social environment

support adolescents in early sampling of a group until they obtain some rewards from the

sampling itself (e.g., invite to band auditions) that motivate attempts at *group entry*.

How Does an Adolescent Join a Preferred Social Group? During *group entry* (Figure

1B), we propose that an adolescent has decided that the potential value of becoming a member of

the group justifies efforts to join it. Importantly, however, one's valuation of the group may have little to do with one's success in joining it, and vigorous or demanding attempts to join may even backfire. To join a group, adolescents should figure out what signals are needed or what resources must be provided. Although we do not make claims regarding how this is learned, it is intuitive that social decision-making involves weighing the value of group membership against the costs of entry attempts. Moreover, groups vary in their degree of openness versus exclusivity, and some groups may expect costly behaviors, such as regular attendance at band practices or certain clothing, that signal status or investment in the group (Dumas et al., 2021; Lang et al., 2022). Entry into some social groups may also depend on skills or knowledge, such as differences in drumming skills required to play in a concert with bandmates.

Attempts at group entry can be costly because social failures and rejection (i.e., social distance) during entry attempts are often strongly negative experiences that can lead to withdrawal and loneliness (Andrews et al., 2021). Social distance is a form of cost that an adolescent incurs not only for attempting to join the group, but also for attempting to form bonds with members of the group. In sum, adolescents use a cost-benefit analysis to estimate the probability of successfully joining a group, adjusting their entry attempts based on the value of resources afforded by group membership and their preferences for these resources. For example, Taylor's attendance at local band performances to impress lead singer Jared before auditions may be worthwhile if the potential resources, like gaining drumming knowledge as a band member, outweigh the required investment (Figure 1B).

How Can an Adolescent Gain the Most Value and Resources from Group Membership? After successfully joining the group, we propose that adolescents track the social value of each group member by learning from the outcomes of resource-relevant social

interactions. Individual bonds often afford unique resources and adolescents may differ in the

extent to which they prefer various types of resources in their social value estimate of an

individual bond. At the outset, adolescents may have only rough approximations of the resources

available from different group members and thus, optimizing their rewards within the group

likely involves sampling interactions with group members and learning which relationships are

most valuable. Repeated interactions reveal insights into the partner's interests and

trustworthiness (Thibaut & Kelley, 1959), informing the adolescent's estimate of the social value

of individual bonds, considering the unique resources they offer (V_{jk}; e.g., Diego provides social

support) and the adolescent's resource preferences (P_k, e.g., music over sports is more valued for

Taylor) (as shown in Equation 2). During *within-group reward sampling* (Figure 1C), the

adolescent learns about the available resources and social value of specific group members

through interactions ("individual reward sensitivity", Table 2), learns about the overall resources

available to group members ("group reward sensitivity", Table 2), and balances exploiting

valuable interactions with familiar members and exploring bonds with unfamiliar group

members to optimize valuable bonds within groups ("social exploration policy", Table 2). These

learned social values then guide decisions about with whom to interact.

What leads an adolescent to explore bonds with an unfamiliar group member?

Adolescent social groups, characterized by members with similar interests and backgrounds (i.e.,

homophily) (McMillan, 2022; McPherson et al., 2001), naturally create interaction contexts for

exploring new social bonds. Existing bonds among group members can facilitate interactions and

introductions that create opportunities to form new bonds (McPherson et al., 2001; Schwyck et

al., 2023). Friend-of-friend dynamics allow adolescents to explore new interactions with

unfamiliar group members that seem random to the individual, but are actually structured by the

existing network ties within the group. As illustrated in Figure 1C, while Taylor initially interacts with the lead singer Jared in learning about the social value of the band, they can subsequently explore new connections with other bandmates like Diego and Kenji. Each person in a dyad has their own estimate of bond valuation, and decisions to interact likely depend on mutual valuation. As adolescents in a group learn about each other from repeated experiences, those who value one another highly will tend to interact more often, potentially affording additional resources such as closeness and intimacy or highly valued experiences (e.g., spending hours recording a new album with a bandmate).

As adolescents learn which individual bonds are more valuable, they transition from exploring other group members to exploiting bonds with preferred group members (as predicted by the softmax policy in Equation 4). In early stages of social-exploit dynamics within a new group, adolescents typically exploit existing bonds with members whom they value most highly, yet they also explore other group members to compare their social values for deciding the direction of their future social interactions. When the social value estimates among group members are similar (Kenji, Diego, and Jared in Figure 1B), the adolescent may randomly explore unfamiliar group members, sampling interactions to learn whether some individual bonds are more beneficial than others. Indeed, relative to other age groups, adolescents are often more novelty-seeking and have higher tolerance for ambiguous conditions with unknown probabilities (Lloyd et al., 2021; Nussenbaum et al., 2023; Somerville et al., 2017). Building on this work, an interesting avenue for future research is examining whether adolescents' versus adults' interaction approach reflect a higher social exploration premium, preferring to interact with unfamiliar group members to learn their social value.

Adolescents likely vary in their preference for how widely they sample a group versus preferring to concentrate on a few relationships (e.g., extraversion versus introversion) (Slobodskaya, 2021). While individuals in groups are sampled in proportion to their learned individual and group value (as predicted by the softmax policy), this exploration rate at the within- and between-group level is controlled by a temperature β parameter that reflects adolescents' tendency for stochastic exploration (Equations 4-5). Lower temperature β values indicate the adolescent more reliably selects relationships which they believe to have the highest social value (i.e., value-driven choices), whereas higher values on β indicate the adolescent more often randomly explores unknown bonds which could be better or worse (i.e., stochastic choices). An adolescent who mostly exploits a single relationship in the group will develop better predictions about the person, potentially experiencing fewer prediction errors (i.e., surprising social outcomes), yet this strategy will likely have little effect on group valuation, particularly in larger groups, if group valuation is indeed the average social value of group members. By comparison, an individual who frequently explores multiple relationships in the group, especially early in learning, will likely experience a more dynamic trajectory of group valuation since large PEs across all individual relationships accumulate in a changing social value estimate of the group. Below, we consider an alternative policy that accounts for the additional role of homophily in shaping these explore-exploit dynamics within groups (Equation 6; *How does an adolescent decide with whom to interact across multiple groups?*).

What leads an adolescent to form closer bonds with a familiar group member?

Learning from positive and negative outcomes in interactions with specific group members is central for friendship formation and dissolution (Thibaut & Kelley, 1959). Adolescents are more likely to form and maintain friendships with peers who continue to reciprocate trust and

resources (Burnett Heyes et al., 2015). Our account suggests that the adolescent updates the

social value of an individual bond based on resource-relevant experiences (Equation 3; "social

flexibility", Table 2). We call this *within-group reward optimization*, where the adolescent seeks

to maximize the group reward rate by preferentially forming individual bonds with the members

who provide the most valued resources. Social experiences often yield reinforcement for

multiple resources (e.g., Diego provides social support and drumming knowledge); thus,

individual valuation updates will apply to each resource as articulated in Equation 3. As shown

in Figure 1C, experiencing better-than-expected outcomes related to resources (PE+; e.g., getting

helpful advice during lunch with Diego) can lead to an upward adjustment in the individual

social value estimate, sustaining future interactions that strengthen the value of that individual

bond that brings known rewards (i.e., exploitation). Conversely, experiencing a string of negative

outcomes related to resources with a group member (repeated PEs-), like consistently not

receiving support from Jared, can weaken the individual bond, prompting the adolescent to

explore bonds with other group members.

We propose that learning from positive and negative experiences with individual

members can shift the overall group's mean social value (Equation 1). However, the adolescent's

estimate of the member's investment to the group, o_{jg}, can modulate the social value estimate of

individual bonds, as more central members may have a greater impact on the dynamics of group

value compared to less central group members (Zingora et al., 2020) (e.g., greater investment to

the group from band leader $o_{jg_{Jared}}$ relative to band mate $o_{jg_{Kenji}}$ in Figure 2A). If preferred

relationships within the group provide reliably positive experiences, the group's overall social

value will also be high, making it worthwhile to maintain one's group membership. Conversely,

repeated sampling of worse than expected social experiences (PEs-) generates a core aspect of

the SEE dilemma: should one resample experiences with other group members in hopes of

finding higher social value or should one invest in other groups altogether? We take up the latter

below (*between-group switches*), but with respect to the former, so long as one stays in the

group, negative PEs will tend to fuel exploration of other relationships in the group while

positive PEs will tend to support sticking with a given relationship.

   How does an adolescent decide with whom to interact across multiple groups? As

illustrated in the above sections, one hypothesis is that social value guides adolescents' choices

about the direction of future interactions across groups through a two-step process: first,

choosing a preferred group, and then selecting specific members within that group who provide

the most valued resources. An alternative hypothesis, however, is that adolescents might

optimize within-group rewards by choosing among all possible individual bonds, influenced by

their valuation, V_j, their tendency for stochastic exploration, β, and the overlap in group

memberships between the person and adolescent, g_j ("with whom should I interact given their

relative value and their overlap in groups of which I am a part?"; Equation 6). Although it

remains an open question how an adolescent learns about the group membership of others, a

higher overlap in group membership g_j (i.e., higher homophily bias) between the adolescent and

other individual likely increases the probability of interacting with them, independent of their

valuation, V_j. Greater overlap with others through self-selected (e.g., band) or involuntary (e.g.,

classrooms) social groups reduces social distance, allowing adolescents more opportunities to

participate in social exchanges to learn each other's social value and resources (Mesch, 2005).

Such biases in meeting opportunities have been shown to explain the emergence of homophily in

high school friendships (Currarini et al., 2009, 2016). As described in Equation 6, the adolescent

decides with whom to interact by comparing the social value of a given person to the value of all

possible individuals (V_m), not just those within the same group (V_g, Equation 4). Research

suggests that adolescents often prioritize interactions based on individual traits and resources,

such as shared interests and perceived social support (Brown & Larson, 2009; Wentzel et al.,

2004), regardless of group affiliation (Hartup & Stevens, 1999). Since individual social value

contributes to bond formation, a higher overlap in groups memberships may lead to more

frequent interactions with highly valued individuals (high homophily bias). Conversely, Taylor

may not consider interacting with socially distant people (low homophily bias), even if they

consider them valuable (e.g., popular student athlete). When homophily bias is moderate, highly

valued group members who are more socially distant may be sampled as often as less valued

partners who are socially close.

Staying or Leaving? Value-Based Between-Group Switches

By adaptively forming and strengthening bonds with high-value group members,

adolescents can maximize their social value at the individual level. This, in turn, can elevate their

position within the broader group network, allowing them to become central members with

considerable influence or access to group resources. Indeed, belonging to a high value group can

reduce the costs of joining other social groups. Well-liked adolescents attract more friends

(Gifford-Smith & Brownell, 2003), broadening their potential support network during

interpersonal difficulties (von Salisch et al., 2014). Compared to those in non-reciprocal

relationships, adolescents with more reciprocal friendships are perceived as having higher

attractiveness and social status (Clark & Ayers, 1988). Importantly, the social value afforded by

group membership is dynamic, not only because one's valuation of others changes with

experience, but also because the group is composed of social agents who are themselves

optimizing their social resources. For instance, as two group members strengthen their bond, it

may inadvertently lead to exclusion of others within the group, limiting access to preferred resources and potentially diminishing the overall value of the group. Additionally, the resources associated with a group may decline if a central aspect of the group's identity, which was previously associated with positive outcomes, loses popularity or relevance (i.e., outcome devaluation). Given limited time, the opportunity cost of maintaining group membership may increase if bonds with group members diminish in value or if one's preferences change (e.g., growing interest in acting pursuits) (Benner et al., 2020). Thus, it is crucial to understand how adolescents arbitrate between competing signals of group valuation from their broader social network and balance membership across multiple groups that maximize their own social value.

How Does an Adolescent Decide Whether to Stay in a Group or Explore Alternatives? Because investing in a social group incurs considerable time and effort costs, it is beneficial to exploit social bonds with high social value if they continue to provide resources at an acceptable rate. When sampling of within-group social value declines, we suggest that the adolescent shifts to a decision rule based on MVT (Equation 7), comparing the group's social value (V_g) with the broader social reward rate of the environment (p). If adolescents' estimate of V_g is commensurate with the average value p of membership in similar groups, they are likely to stay within their current group (Equation 7; "between-group switches", Table 2). However, if sizable negative shifts in V_g occur and the expected group value declines, adolescents might benefit more by sampling alternative groups. By noticing changes in the group's social value V_g, and weighing it against the costs of sampling from a new group with a potential value p, adolescents can form a reasonable estimate of the entry and exit costs associated with staying in their current group or exploring new groups altogether.

Our application of MVT characterizes staying versus leaving dynamics based not only on value, but also on the opportunity costs of time h spent investing in new groups (e.g., *early group sampling and group entry dynamics*) and the rate of local depletion of social resources k over time. Importantly, the decision to leave one group to explore alternatives often involves considering groups where one's priors are relatively uninformative. While MVT typically emphasizes the metabolic costs of leaving, the corollary in the SEE dilemma is the estimated entry costs of alternative groups, as well as the potential social fallout of leaving. We propose that adolescents maintain broad estimates of the average social value p available ("what resources could I gain from affiliating with a new "average" social group?)*,* and costs h ("how much time and effort will it take to get into a new group?") that guide between-group switches (Figure 2A). Each adolescent likely has their own distinct *leaving threshold,* the point at which they disengage from within-group reward optimization*,* travel to a new group, and initiate early group sampling and group entry attempts in the new group (Figure 2B).

A healthy social capital portfolio likely involves balancing preferred social resources, typically by allocating effort across multiple groups and relationships. While band members are rich sources of musical knowledge and popularity, Taylor's experience may reveal that resources like social support are best acquired elsewhere. By staying "local" and building stronger bonds within groups, adolescents can benefit from the group's resources and the social value of relationships in which they have already invested considerable time (Clark & Ayers, 1988; Gifford-Smith & Brownell, 2003). On the other hand, adolescents whose social connections are distributed across multiple groups tend to have a higher quality and quantity of social bonds with diverse resources (Iyer et al., 2009). Decisions about a large space of possible social interactions can be guided by MVT at a group level ("is what I am sampling better than the local

alternatives?"). Comparing the values of alternative groups is a much simpler problem than comparing the values of all individuals in one's network, many of whom may be members of more than one group. It is thus beneficial to leave a group when its social value is declining, which supports social value maximization (Kolling & Akam, 2017).

Extensions and Limitations of the SEE Framework

The SEE framework advances theoretical and experimental work on social decision-making in adolescence by formalizing how value computations that underlie associative learning (Behrens et al., 2008; Olsson et al., 2020) explain how adolescents form social bonds within groups and manage memberships across multiple groups. We propose that adolescents track and pursue preferred resources within groups, making value-guided choices that drive increased exploration. SEE also offers predictions about how group membership and homophily constrains the tendency to sample interactions within the group. Finally, comparing the group's value to the value of resources in the overall environment guide decisions to stay in one group or explore better alternatives. Our account offers one set of explanations for how social value guides explore-exploit decision-making in adolescence, but model extensions and novel experiments may be necessary to capture the learning dynamics of social behavior across development.

Modeling SEE Beyond Value

While our account's emphasis on social value is a strength that allows for links between formal models of exploration, value-based exploration can be constrained by changes in costs, punishments, or resource scarcity (Addicott et al., 2017). Investing in social groups can increase their value over time, but this is not always the case. Social resources could be depleted by the same behaviors that generate value, such as excessive communication or seeking support so often that others withdraw. Negative prediction errors in within-group sampling partially

addresses these constraints, but our framework does not address this between groups. This could

perhaps be described by depletion (k) in MVT, where the resources the group affords decrease

with each interaction (Wajnberg et al., 2000). However, "depletion" may also result from signals

that potential rewards elsewhere are increasing relative to the group value (p is increasing

relative to V_g), suggesting leaving might provide more desired resources than staying in the

current group. If Taylor sees other local bands gaining popularity and holding auditions, leaving

the current group might confer more desired resources. Indeed, prior work suggest extensions to

MVT are often needed to capture optimal foraging behavior. For example, "overharvesting" is

better explained by decision-making models that additionally emphasize building representations

of environmental structures and available rewards (Harhen & Bornstein, 2023). These dynamics

might align with our value-driven reward sampling and optimization processes.

Our current model treats group membership as binary: one is a member or not a member.

However, it is likely that group membership is best represented as graded, particularly when the

cost of membership is low (Granovetter, 1973; Sandstrom & Dunn, 2014). Others are also not

assigned solely to one group but might have membership in several overlapping groups,

especially if they are close friends. Thus, if a peer is a member of two of the same groups as the

adolescent, our current account does not make predictions about how the adolescent assigns

credit for experiences with that person to the appropriate group. An interesting extension to the

SEE account would be considering whether the social value estimate of an individual bond, V_j, is

inversely weighted by social distance, such that even if a person possesses preferred resources

but is hard to access, the relationship is not preferred. In contrast to the role of homophily bias in

choices about with whom to interact (Equation 6), social distance could also bias the *value* of the

individual bond by overlap in group membership. Social distance might be estimated by group

overlap, as well as dyadic connection based on familiarity (independent of resources; e.g.,

childhood friends) (Bzdok & Dunbar, 2020). Model extensions that allow for a relationship-

specific valuation bonus can capture the suppression or amplification of bond valuation based on

group overlap or dyadic connection. For example, Taylor may not value people with whom they

have little group membership overlap, even after good experiences (e.g., jam session with an

acquaintance). Future work should test this alternative formalism of individual valuation to

determine its validity and implications for adolescent social behavior.

Finally, we do not consider developmental differences in learning rate as a mechanism

for heightened exploration in adolescence. Age-related differences in learning rates from

adolescence to adulthood would suggest adolescents integrate recent experiences more than

adults (Decker et al., 2015). However, there is mixed evidence regarding the direction of the

learning rate's association with explorative dynamics across age (Topel et al., 2023). Therefore,

further research is needed to determine whether adolescents have meaningfully higher learning

rates, or whether an alternative construct better captures (directed) exploration dynamics.

Perhaps learning rates are part of the account, but the strategy used to identify value signals has

additional specifiers. For example, a high learning rate implies adolescents learn more from all

value signals. Building on Equation 6, if choices to explore are additionally modulated by the

adolescent's preferences for certain resources (P_k), and estimation of overlap in group

membership (g_j), a high learning rate might interact with preferences such that adolescents will

interact less with group members who provide less desired resources. For example, our previous

research suggests adolescents are differentially motivated by social signals from parents versus

peers (Do & Telzer, 2024). Another possibility is that developmental differences in social

exploration are better explained by alternative models, such as a exploitation-based model that

prioritizes learning from previously rewarding outcomes or a model that considers learning from chosen and unchosen outcomes equally (Chierchia et al., 2023).

Experimental Tests

Initial studies have examined lifespan differences in nonsocial stay-or-leave decisions according to MVT (Constantino & Daw, 2015; Lloyd et al., 2021). Extending experimental paradigms of stay-or-leave decisions to *social* contexts is necessary to test if adolescents are more willing to leave their current social patch and explore new ones, while adults may prefer longer harvesting times or lower leaving thresholds. Because the social value of peers strongly influences adolescent behavior (Do & Telzer, 2024; van den Berg et al., 2020), studies examining the prioritization of social value and its associated resources might show that adolescents are especially motivated to maximize social value via exploration and set higher leaving thresholds than adults. In adults, leaving thresholds might be relatively low (i.e., they stay until resources are heavily depleted) because of the value of established social groups. Developmental studies using foraging paradigms support this possibility in nonsocial contexts (Lloyd et al., 2021; Nussenbaum et al., 2020; Somerville et al., 2017).

An opportunity to capture within-group social dynamics may lie in rethinking the design of social decision-making experimental paradigms. While many tasks used with adolescents provide passive information about others (e.g., other's preferences or status), few require motivated effort to reveal social information relevant to decision-making. To test SEE in adolescence, constructing experimental tasks that model bidirectional social dynamics will help us understand how social connections are formed and maintained through reinforcement. Like group memberships, dyadic relationships generate abundant social resources related to intimacy, acceptance, and belongingness (Bowker & Weingarten, 2022). However, this is challenging

when multiple participants in a social interaction serve both as reinforcers and are mutually reinforced by each other over the course of repeated interactions. One promising avenue is to combine coupled-oscillator models that are common in the literature on affective coregulation in relationships (Schreiber et al., 2021) with RL models to capture the simultaneous valuation of social closeness with counterparts in dyadic interactions. Such models can produce ratings of social closeness that mutually influence one another, which may better characterize the learning dynamics within reciprocal friendships in adolescence.

Limitations and Future Directions

Although the current developmental computational framework aims to provide a broad foundation for understanding adolescent social behavior in groups from a value-based decision-making perspective, future research will need to test more specific components of social explore-exploit decision-making. The SEE theory is not (yet) a single computational model, but an initial effort to formalize predictions regarding social explore-exploit learning during adolescence, which can be refined into specific models for simulation and empirical validation. Starting with a narrower model focused solely on within-group or between-group learning dynamics would limit our ability to address key questions about adolescent social decision-making within the RL and MVT frameworks. Individual bond valuation is constrained by group membership, which in turn affects how adolescents balance memberships across multiple groups. Thus, our comprehensive approach is a necessary first step toward understanding adolescent social interactions and their impact on psychosocial functioning.

Maintaining a diverse portfolio of social resources is important for social functioning, but it remains unclear how resources of different types are compared in value and how an individual balances other goals met by these resources (e.g., access to potential romantic partners versus

social status). The inverse relationship between socioeconomic status and communal bonds is

one example of this tradeoff at a societal level, but a future direction for SEE will be

incorporating these tradeoffs at the individual level (Chetty et al., 2022a). We suggest that

characterizing social resource diversification will require integrating the ecology literature for

elaborated accounts of how organisms decide between multiple resource types within foraging

(Simpson et al., 2004) using estimates of social value (Villalonga-Olives & Kawachi, 2015). For

example, theoretical models of how nutrient intake tradeoffs are optimized in animal species

could provide a starting point for pursuing and maximizing access to different types of resources

(Houston et al., 2011; Simpson et al., 2004).

Another important future direction for testing the SEE framework lies in modeling

individual differences in exploratory behavior. Although we believe SEE will capture tendencies

to switch patches frequently versus rarely, the tendency for stochastic exploration varies across

non-human and human individuals (Reader, 2015). Differences in foraging dynamics can relate

to differences in individual preferences, result from environmental pressures, or relate to biases

shaped through learning and experience (Lewis et al., 1990). Individual difference factors (e.g.,

personality) are known to impact the subjective value of social rewards (Krautter et al., 2023).

Adolescents will make different choices based on their preferences for each resource and how

much they value each group (e.g., joining a band versus a group that could help them get a date).

Personality research suggests that trait-level differences in reward sensitivity and valuation may

influence this decision tradeoff (Smillie, 2013). Specifically, the personality domain of

extraversion has been linked to neuromodulators of exploration dynamics (DeYoung, 2013),

which may be relevant for testing SEE in adolescence. Moreover, individual differences in social

exploration in adolescents versus adults may have important implications for understanding the

worsening mental health crisis among young people (Goodwin et al., 2022; Twenge et al., 2021).

Adolescents worldwide are increasingly struggling with loneliness, which often arises from

difficulties in building social connection, and may be partially explained by maladaptive

exploration strategies in social contexts (Addicott et al., 2017).

Broader Implications and Conclusions

Developing strong social networks and relationships during adolescence is vital for

effective interpersonal functioning in adulthood. Failing to develop close relationships and social

support in adolescence hinders adult interpersonal functioning and contributes to crucial

problems such as loneliness and depression (Ribeiro et al., 2023; Twenge et al., 2021). But how

do adolescents decide with which social groups to interact and which individuals within those

groups are worth forming stronger bonds? Our developmental computational account of such

social explore-exploit dilemmas posits that adolescents seek to explore and maximize the value

of potential sources of social capital by building beneficial individual and group bonds. The

overall value of group membership is learned and updated based on past interactions within the

group that provide the most valued resources. To maximize the group reward rate, adolescents

track the social value of group members by learning from the outcomes of social interactions in

terms of the resources they afford, flexibly adjusting their future interactions to preferentially

maintain bonds with highly valued group members. Because the social value afforded by

individual bonds or group membership changes with experience, adolescents should maximize

the value of their own social capital portfolio by preferentially maintaining memberships in the

groups that collectively provide the most valued resources. Our account provides important new

directions for examining the dynamics of adolescent behavior in social groups and understanding

how various forms of social capital can support positive relationships into adulthood.

Belonging to multiple diverse social groups during adolescence not only fosters essential social skills for adulthood, but also provides access to high-quality social resources that they could otherwise not uncover alone. Investing in high-status groups and balancing membership across multiple groups in adolescence plays a crucial role in building a strong, supportive social network. This network of diverse relationships affords collective resources and advantages, such as increased social belonging and reciprocity, access to tightly-knit community resources, and exposure to new information and perspectives (Alaa et al., 2018). Memberships across multiple social groups promote a richer, integrated social network that increases stability in life transitions (Iyer et al., 2009) and improves health outcomes (Ehsan et al., 2019). On the other hand, lacking stable or supportive social networks can lead to isolation and increased risk for psychosocial challenges in adulthood (Lieberz et al., 2021).

Learning from positive and negative experiences with individuals within a social group facilitates the development and rehearsal of key interpersonal skills that are important for healthy adult relationships, such as perspective taking, conflict resolution, and compromise (Kumar et al., 2019). Choosing friendships and romantic relationships based on social value can lead to more stable and higher-quality relationships and a supportive social network. Because resource allocation becomes increasingly tied to the type and strength of social bonds from middle to late adolescence (Burnett Heyes et al., 2015), forming connections with trustworthy group members can increase access to the group's social resources (van de Groep et al., 2020). Thus, directing investment towards positive and rewarding connections who are likely to share and reciprocate resources during adolescence is key to sustaining the social capital embedded in these relationships for healthy interpersonal functioning in adulthood.

References

Addicott, M. A., Pearson, J. M., Sweitzer, M. M., Barack, D. L., & Platt, M. L. (2017). A primer on foraging and the explore/exploit trade-off for psychiatry research. *Neuropsychopharmacology*, *42*(10), 1931–1939.

Alaa, A. M., Ahuja, K., & Schaar, M. van der. (2018). A Micro-Foundation of Social Capital in Evolving Social Networks. *IEEE Transactions on Network Science and Engineering*, *5*(1), 14–31. https://doi.org/10.1109/TNSE.2017.2729782

Aldrich, D. P., & Meyer, M. A. (2015). Social Capital and Community Resilience. *American Behavioral Scientist*, *59*(2), 254–269. https://doi.org/10.1177/0002764214550299

Almquist, Y. (2009). Peer status in school and adult disease risk: A 30-year follow-up study of disease-specific morbidity in a Stockholm cohort. *Journal of Epidemiology and Community Health*, *63*(12), 1028–1034. https://doi.org/10.1136/jech.2009.088377

Andrews, J. L., Ahmed, S. P., & Blakemore, S.-J. (2021). Navigating the Social Environment in Adolescence: The Role of Social Brain Development. *Biological Psychiatry*, *89*(2), 109–118. https://doi.org/10.1016/j.biopsych.2020.09.012

Behrens, T. E. J., Hunt, L. T., Woolrich, M. W., & Rushworth, M. F. S. (2008). Associative learning of social value. *Nature*, *456*(7219), Article 7219. https://doi.org/10.1038/nature07538

Benner, A. D., Hou, Y., & Jackson, K. M. (2020). The Consequences of Friend-Related Stress Across Early Adolescence. *The Journal of Early Adolescence*, *40*(2), 249–272. https://doi.org/10.1177/0272431619833489

Black, R. W. (2005). Access and Affiliation: The Literacy and Composition Practices of English-Language Learners in an Online Fanfiction Community. *Journal of Adolescent & Adult Literacy*, *49*(2), 118–128. https://doi.org/10.1598/JAAL.49.2.4

Blakemore, S.-J., & Mills, K. L. (2014). Is Adolescence a Sensitive Period for Sociocultural Processing? *Annual Review of Psychology*, *65*(1), 187–207. https://doi.org/10.1146/annurev-psych-010213-115202

Bourdieu, P., & Wacquant, L. (1992). *Réponses* (Vol. 4). Paris: Seuil.

Bowker, J. C., & Weingarten, J. (2022). Temporal approaches to the study of friendship: Understanding the developmental significance of friendship change during childhood and adolescence. In J. J. Lockman (Ed.), *Advances in Child Development and Behavior* (Vol. 63, pp. 251–272). Academic Press.

Brown, B. B., & Larson, J. (2009). Peer Relationships in Adolescence. In *Handbook of Adolescent Psychology*. John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470479193.adlpsy002004

Burnett Heyes, S., Jih, Y., Block, P., Hiu, C., Holmes, E. A., & Lau, J. Y. F. (2015). Relationship Reciprocation Modulates Resource Allocation in Adolescent Social Networks: Developmental Effects. *Child Development*, *86*(5), 1489–1506. https://doi.org/10.1111/cdev.12396

Cairns, R. B., Perrin, J. E., & Cairns, B. D. (1985). Social Structure and Social Cognition in Early Adolescence: Affiliative Patterns. *The Journal of Early Adolescence*, *5*(3), 339–355. https://doi.org/10.1177/0272431685053007

Capella, J., Jorgensen, N. A., Kwon, S.-J., Maza, M. T., Prinstein, M. J., Lindquist, K. A., & Telzer, E. H. (2023). Adolescents' neural sensitivity to high and low popularity:

Longitudinal links to risk-taking and prosocial behavior. *Developmental Cognitive Neuroscience*, *63*, 101290. https://doi.org/10.1016/j.dcn.2023.101290

Charnov, E. L. (1976). Optimal foraging, the marginal value theorem. *Theoretical Population Biology*, *9*(2), 129–136.

Chein, J., Albert, D., O'Brien, L., Uckert, K., & Steinberg, L. (2011). Peers increase adolescent risk taking by enhancing activity in the brain's reward circuitry. *Developmental Science*, *14*(2), F1-10. https://doi.org/10.1111/j.1467-7687.2010.01035.x

Chetty, R., Jackson, M. O., Kuchler, T., Stroebel, J., Hendren, N., Fluegge, R. B., Gong, S., Gonzalez, F., Grondin, A., Jacob, M., Johnston, D., Koenen, M., Laguna-Muggenburg, E., Mudekereza, F., Rutter, T., Thor, N., Townsend, W., Zhang, R., Bailey, M., … Wernerfelt, N. (2022a). Social capital I: Measurement and associations with economic mobility. *Nature*, *608*(7921), 108–121. https://doi.org/10.1038/s41586-022-04996-4

Chetty, R., Jackson, M. O., Kuchler, T., Stroebel, J., Hendren, N., Fluegge, R. B., Gong, S., Gonzalez, F., Grondin, A., Jacob, M., Johnston, D., Koenen, M., Laguna-Muggenburg, E., Mudekereza, F., Rutter, T., Thor, N., Townsend, W., Zhang, R., Bailey, M., … Wernerfelt, N. (2022b). Social capital II: Determinants of economic connectedness. *Nature*, *608*(7921), 122–134. https://doi.org/10.1038/s41586-022-04997-3

Chierchia, G., Soukupová, M., Kilford, E. J., Griffin, C., Leung, J., Palminteri, S., & Blakemore, S.-J. (2023). Confirmatory reinforcement learning changes with age during adolescence. *Developmental Science*, *26*(3), e13330. https://doi.org/10.1111/desc.13330

Clark, M. L., & Ayers, M. (1988). The role of reciprocity and proximity in junior high school friendships. *Journal of Youth and Adolescence*, *17*(5), 403–411. https://doi.org/10.1007/BF01537882

Clutton-Brock, T. (2021). Social evolution in mammals. *Science*, *373*(6561), eabc9699. https://doi.org/10.1126/science.abc9699

Coleman, J. S. (1988). Social Capital in the Creation of Human Capital. *American Journal of Sociology*, *94*, S95–S120. JSTOR.

Constantino, S. M., & Daw, N. D. (2015). Learning the opportunity cost of time in a patch-foraging task. *Cognitive, Affective, & Behavioral Neuroscience*, *15*(4), 837–853. https://doi.org/10.3758/s13415-015-0350-y

Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social–affective engagement and goal flexibility. *Nature Reviews Neuroscience*, *13*(9), Article 9. https://doi.org/10.1038/nrn3313

Currarini, S., Jackson, M. O., & Pin, P. (2009). An Economic Model of Friendship: Homophily, Minorities, and Segregation. *Econometrica*, *77*(4), 1003–1045. https://doi.org/10.3982/ECTA7528

Currarini, S., Matheson, J., & Vega-Redondo, F. (2016). A simple model of homophily in social networks. *European Economic Review*, *90*, 18–39. https://doi.org/10.1016/j.euroecorev.2016.03.011

Davidow, J. Y., Foerde, K., Galván, A., & Shohamy, D. (2016). An Upside to Reward Sensitivity: The Hippocampus Supports Enhanced Reinforcement Learning in Adolescence. *Neuron*, *92*(1), 93–99. https://doi.org/10.1016/j.neuron.2016.08.031

Decker, J. H., Lourenco, F. S., Doll, B. B., & Hartley, C. A. (2015). Experiential reward learning outweighs instruction prior to adulthood. *Cognitive, Affective, & Behavioral Neuroscience*, *15*(2), 310–320. https://doi.org/10.3758/s13415-014-0332-5

Delgado, M. R., Fareri, D. S., & Chang, L. J. (2023). Characterizing the mechanisms of social connection. *Neuron*, *111*(24), 3911–3925. https://doi.org/10.1016/j.neuron.2023.09.012

DePasque, S., & Galván, A. (2017). Frontostriatal development and probabilistic reinforcement learning during adolescence. *Neurobiology of Learning and Memory*, *143*, 1–7. https://doi.org/10.1016/j.nlm.2017.04.009

DeYoung, C. G. (2013). The neuromodulator of exploration: A unifying theory of the role of dopamine in personality. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00762

Do, K. T., McCormick, E. M., & Telzer, E. H. (2020). Neural sensitivity to conflicting attitudes supports greater conformity toward positive over negative influence in early adolescence. *Developmental Cognitive Neuroscience*, *45*, 100837. https://doi.org/10.1016/j.dcn.2020.100837

Do, K. T., & Telzer, E. H. (2024). Longitudinal Changes in the Value and Influence of Parent and Peer Attitudes about Externalizing Behaviors across Adolescence. *Developmental Psychology*. https://doi.org/10.31219/osf.io/6uh3d

Dumas, M., Barker, J. L., & Power, E. A. (2021). When does reputation lie? Dynamic feedbacks between costly signals, social capital and social prominence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *376*(1838), 20200298. https://doi.org/10.1098/rstb.2020.0298

Dunphy, D. C. (1963). The Social Structure of Urban Adolescent Peer Groups. *Sociometry*, *26*(2), 230–246. https://doi.org/10.2307/2785909

Ehsan, A., Klaas, H. S., Bastianen, A., & Spini, D. (2019). Social capital and health: A systematic review of systematic reviews. *SSM - Population Health*, *8*, 100425. https://doi.org/10.1016/j.ssmph.2019.100425

Emler, N. (1994). Gossip, reputation, and social adaptation. *Good Gossip.*, 117–138.

Fareri, D. S., Chang, L. J., & Delgado, M. R. (2015). Computational Substrates of Social Value in Interpersonal Collaboration. *Journal of Neuroscience*, *35*(21), 8170–8180. https://doi.org/10.1523/JNEUROSCI.4775-14.2015

Fareri, D. S., Niznikiewicz, M. A., Lee, V. K., & Delgado, M. R. (2012). Social network modulation of reward-related signals. *The Journal of Neuroscience*, *32*(26), 9045–9052. https://doi.org/10.1523/JNEUROSCI.0610-12.2012

Foulkes, L., & Blakemore, S.-J. (2016). Is there heightened sensitivity to social reward in adolescence? *Current Opinion in Neurobiology*, *40*, 81–85. https://doi.org/10.1016/j.conb.2016.06.016

Fournier, M. A., David, D. S. M., & Zuroff, D. C. (2010). Origins and Applications of the Interpersonal Circumplex. In L. M. Horowitz & S. Strack (Eds.), *Handbook of Interpersonal Psychology* (1st ed., pp. 57–73). Wiley. https://doi.org/10.1002/9781118001868.ch4

Frankenhuis, W. E., & Gopnik, A. (2023). Early adversity and the development of explore– exploit tradeoffs. *Trends in Cognitive Sciences*, S1364661323000918. https://doi.org/10.1016/j.tics.2023.04.001

Gabay, A. S., & Apps, M. A. J. (2021). Foraging optimally in social neuroscience: Computations and methodological considerations. *Social Cognitive and Affective Neuroscience*, *16*(8), 782–794. https://doi.org/10.1093/scan/nsaa037

Gifford-Smith, M. E., & Brownell, C. A. (2003). Childhood peer relationships: Social acceptance, friendships, and peer networks. *Journal of School Psychology*, *41*(4), 235–284. https://doi.org/10.1016/S0022-4405(03)00048-7

Giraldeau, L.-A., & Dubois, F. (2008). Chapter 2 Social Foraging and the Study of Exploitative Behavior. In *Advances in the Study of Behavior* (Vol. 38, pp. 59–104). Elsevier. https://doi.org/10.1016/S0065-3454(08)00002-8

Glanville, J. L., & Bienenstock, E. J. (2009). A Typology for Understanding the Connections Among Different Forms of Social Capital. *American Behavioral Scientist*, *52*(11), 1507–1530. https://doi.org/10.1177/0002764209331524

Goldstone, R. L., & Gureckis, T. M. (2009). Collective Behavior. *Topics in Cognitive Science*, *1*(3), 412–438. https://doi.org/10.1111/j.1756-8765.2009.01038.x

Goodwin, R. D., Dierker, L. C., Wu, M., Galea, S., Hoven, C. W., & Weinberger, A. H. (2022). Trends in U.S. Depression Prevalence From 2015 to 2020: The Widening Treatment Gap. *American Journal of Preventive Medicine*, *63*(5), 726–733. https://doi.org/10.1016/j.amepre.2022.05.014

Gopnik, A. (2020). Childhood as a solution to explore–exploit tensions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*(1803), 20190502. https://doi.org/10.1098/rstb.2019.0502

Goza, F., & Ryabov, I. (2009). Adolescents' educational outcomes: Racial and ethnic variations in peer network importance. *Journal of Youth and Adolescence*, *38*, 1264–1279.

Granovetter, M. S. (1973). The Strength of Weak Ties. *American Journal of Sociology*, *78*(6), 1360–1380.

Harhen, N. C., & Bornstein, A. M. (2023). Overharvesting in human patch foraging reflects rational structure learning and adaptive planning. *Proceedings of the National Academy of Sciences*, *120*(13), e2216524120. https://doi.org/10.1073/pnas.2216524120

Hartup, W. W. (1992). Conflict and friendship relations. *Conflict in Child and Adolescent Development*, 186–215.

Hartup, W. W., & Stevens, N. (1999). Friendships and Adaptation Across the Life Span. *Current Directions in Psychological Science*, *8*(3), 76–79. https://doi.org/10.1111/1467-8721.00018

Hayden, B. Y., Pearson, J. M., & Platt, M. L. (2011). Neuronal basis of sequential foraging decisions in a patchy environment. *Nature Neuroscience*, *14*(7), 933–939. https://doi.org/10.1038/nn.2856

Heyes, C. (2012). What's social about social learning? *Journal of Comparative Psychology*, *126*(2), 193–202. https://doi.org/10.1037/a0025180

Heyes, C. (2016). Who Knows? Metacognitive Social Learning Strategies. *Trends in Cognitive Sciences*, *20*(3), 204–213. https://doi.org/10.1016/j.tics.2015.12.007

Hommerich, C., & Tiefenbach, T. (2018). Analyzing the Relationship Between Social Capital and Subjective Well-Being: The Mediating Role of Social Affiliation. *Journal of Happiness Studies*, *19*(4), 1091–1114. https://doi.org/10.1007/s10902-017-9859-9

Hopwood, C. J., Pincus, A. L., & Wright, A. G. C. (2021). Six assumptions of contemporary integrative interpersonal theory of personality and psychopathology. *Current Opinion in Psychology*, *41*, 65–70. https://doi.org/10.1016/j.copsyc.2021.03.007

Houston, A. I., Higginson, A. D., & McNamara, J. M. (2011). Optimal foraging for multiple nutrients in an unpredictable environment: Foraging for multiple nutrients. *Ecology Letters*, *14*(11), 1101–1107. https://doi.org/10.1111/j.1461-0248.2011.01678.x

Hrdy, S. B. (2011). *Mothers and Others: The Evolutionary Origins of Mutual Understanding*. Harvard University Press. https://www.hup.harvard.edu/books/9780674060326

Iyer, A., Jetten, J., Tsivrikos, D., Postmes, T., & Haslam, S. A. (2009). The more (and the more compatible) the merrier: Multiple group memberships and identity compatibility as predictors of adjustment after life transitions. *British Journal of Social Psychology*, *48*(4), 707–733. https://doi.org/10.1348/014466608X397628

Jetten, J., Branscombe, N. R., Haslam, S. A., Haslam, C., Cruwys, T., Jones, J. M., Cui, L., Dingle, G., Liu, J., Murphy, S., Thai, A., Walter, Z., & Zhang, A. (2015). Having a Lot of a Good Thing: Multiple Important Group Memberships as a Source of Self-Esteem. *PLOS ONE*, *10*(5), e0124609. https://doi.org/10.1371/journal.pone.0124609

Jolly, E., & Chang, L. J. (2021). Gossip drives vicarious learning and facilitates social connection. *Current Biology*, *31*(12), 2539-2549.e6. https://doi.org/10.1016/j.cub.2021.03.090

Kang, S. K., & Bodenhausen, G. V. (2015). Multiple Identities in Social Perception and Interaction: Challenges and Opportunities. *Annual Review of Psychology*, *66*(1), 547–574. https://doi.org/10.1146/annurev-psych-010814-015025

Kindschi, M., Cieciuch, J., Davidov, E., Ehlert, A., Rauhut, H., Tessone, C. J., & Algesheimer, R. (2019). Values in adolescent friendship networks. *Network Science*, *7*(4), 498–522. https://doi.org/10.1017/nws.2019.16

Kolling, N., & Akam, T. (2017). (Reinforcement?) Learning to forage optimally. *Current Opinion in Neurobiology*, *46*(Supplement C), 162–169. https://doi.org/10.1016/j.conb.2017.08.008

Koski, J. E., Xie, H., & Olson, I. R. (2015). Understanding social hierarchies: The neural and psychological foundations of status perception. *Social Neuroscience*, *10*(5), 527–550. https://doi.org/10.1080/17470919.2015.1013223

Krautter, K., Büchner, A., & Jachimowicz, J. M. (2023). Extraverts Reap Greater Social Rewards From Passion Because They Express Passion More Frequently and More Diversely. *Personality and Social Psychology Bulletin*, 01461672231211843. https://doi.org/10.1177/01461672231211843

Kreager, D. A., Rulison, K., & Moody, J. (2011). Delinquency and the Structure of Adolescent Peer Groups*. *Criminology*, *49*(1), 95–127. https://doi.org/10.1111/j.1745-9125.2010.00219.x

Kumar, P., Pisoni, A., Bondy, E., Kremens, R., Singleton, P., Pizzagalli, D. A., & Auerbach, R. P. (n.d.). Delineating the Social Valuation Network in Adolescents. *Social Cognitive and Affective Neuroscience*. https://doi.org/10.1093/scan/nsz086

Lang, M., Chvaja, R., Grant Purzycki, B., Václavík, D., & Staněk, R. (2022). Advertising cooperative phenotype through costly signals facilitates collective action. *Royal Society Open Science*, *9*(5), 202202. https://doi.org/10.1098/rsos.202202

Lewis, W. J., Vet, L. E. M., Tumlinson, J. H., Van Lenteren, J. C., & Papaj, D. R. (1990). Variations in Parasitoid Foraging Behavior: Essential Element of a Sound Biological Control Theory. *Environmental Entomology*, *19*(5), 1183–1193. https://doi.org/10.1093/ee/19.5.1183

Lieberz, J., Shamay-Tsoory, S. G., Saporta, N., Esser, T., Kuskova, E., Stoffel-Wagner, B., Hurlemann, R., & Scheele, D. (2021). Loneliness and the Social Brain: How Perceived Social Isolation Impairs Human Interactions. *Advanced Science*, *8*(21), 2102076. https://doi.org/10.1002/advs.202102076

Lin, N. (2007). *Social capital: A theory of social structure and action* (Repr). Cambridge Univ. Pr.

Lin, S.-W., & Lo, L. Y.-S. (2015). Mechanisms to motivate knowledge sharing: Integrating the reward systems and social network perspectives. *Journal of Knowledge Management*, *19*(2), 212–235. https://doi.org/10.1108/JKM-05-2014-0209

Lloyd, A., McKay, R., Sebastian, C. L., & Balsters, J. H. (2021). Are adolescents more optimal decision-makers in novel environments? Examining the benefits of heightened exploration in a patch foraging paradigm. *Developmental Science*, *24*(4), e13075. https://doi.org/10.1111/desc.13075

Mannes, A. E., Soll, J. B., & Larrick, R. P. (2014). The wisdom of select crowds. *Journal of Personality and Social Psychology*, *107*(2), 276.

Martins, D., Rademacher, L., Gabay, A. S., Taylor, R., Richey, J. A., Smith, D. V., Goerlich, K. S., Nawijn, L., Cremers, H. R., Wilson, R., Bhattacharyya, S., & Paloyelis, Y. (2021). Mapping social reward and punishment processing in the human brain: A voxel-based meta-analysis of neuroimaging findings using the social incentive delay task. *Neuroscience & Biobehavioral Reviews*, *122*, 1–17. https://doi.org/10.1016/j.neubiorev.2020.12.034

McMillan, C. (2022). Strong and weak tie homophily in adolescent friendship networks: An analysis of same-race and same-gender ties. *Network Science*, *10*(3), 283–300. https://doi.org/10.1017/nws.2022.24

McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001). Birds of a Feather: Homophily in Social Networks. *Annual Review of Sociology*, *27*, 415–444. JSTOR.

Mesch, G. (2005). A Study of Adolescents' Online and Offline Social Relationships. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.1308494

Muscatell, K. A., Merritt, C. C., Cohen, J. R., Chang, L., & Lindquist, K. A. (2022). The Stressed Brain: Neural Underpinnings of Social Stress Processing in Humans. *Current Topics in Behavioral Neurosciences*, *54*, 373–392. https://doi.org/10.1007/7854_2021_281

Nussenbaum, K., Cohen, A. O., Davis, Z. J., Halpern, D. J., Gureckis, T. M., & Hartley, C. A. (2020). Causal Information-Seeking Strategies Change Across Childhood and Adolescence. *Cognitive Science*, *44*(9). https://doi.org/10.1111/cogs.12888

Nussenbaum, K., Martin, R. E., Maulhardt, S., Yang, Y. (Jen), Bizzell-Hatcher, G., Bhatt, N. S., Koenig, M., Rosenbaum, G. M., O'Doherty, J. P., Cockburn, J., & Hartley, C. A. (2023). Novelty and uncertainty differentially drive exploration across development. *eLife*, *12*, e84260. https://doi.org/10.7554/eLife.84260

Olsson, A., Knapska, E., & Lindström, B. (2020). The neural and computational systems of social learning. *Nature Reviews Neuroscience*, *21*(4), Article 4. https://doi.org/10.1038/s41583-020-0276-4

Pearrow, M., Sander, J., & Jones, J. (2019). Comparing communities: The cultural characteristics of ethnic social capital. *Education and Urban Society*, *51*(6), 739–755.

Putnam, R. (2001). Social capital: Measurement and consequences. *Canadian Journal of Policy Research*, *2*(1), 41–51.

Ragelienė, T. (2016). Links of Adolescents Identity Development and Relationship with Peers: A Systematic Literature Review. *Journal of the Canadian Academy of Child and Adolescent Psychiatry = Journal De l'Academie Canadienne De Psychiatrie De L'enfant Et De L'adolescent*, *25*(2), 97–105.

Reader, S. M. (2015). Causes of Individual Differences in Animal Exploration and Search. *Topics in Cognitive Science*, *7*(3), 451–468. https://doi.org/10.1111/tops.12148

Rendell, L., Boyd, R., Cownden, D., Enquist, M., Eriksson, K., Feldman, M. W., Fogarty, L., Ghirlanda, S., Lillicrap, T., & Laland, K. N. (2010). Why Copy Others? Insights from the Social Learning Strategies Tournament. *Science*, *328*(5975), 208–213. https://doi.org/10.1126/science.1184719

Ribeiro, O., Freitas, M., Rubin, K. H., & Santos, A. J. (2023). Loneliness Profiles in Adolescence: Associations with Sex and Social Adjustment to the Peer Group. *Journal of Child and Family Studies*, *32*(4), 1204–1217. https://doi.org/10.1007/s10826-022-02472-1

Rojek-Giffin, M., Lebreton, M., Daunizeau, J., Fariña, A., Gross, J., & De Dreu, C. K. W. (2023). Learning rules of engagement for social exchange within and between groups. *Proceedings of the National Academy of Sciences*, *120*(19), e2218443120. https://doi.org/10.1073/pnas.2218443120

Ruel, A., Devine, S., & Eppinger, B. (2021). Resource-rational approach to meta-control problems across the lifespan. *WIREs Cognitive Science*, *12*(5). https://doi.org/10.1002/wcs.1556

Sandstrom, G. M., & Dunn, E. W. (2014). Social Interactions and Well-Being: The Surprising Power of Weak Ties. *Personality and Social Psychology Bulletin*, *40*(7), 910–922. https://doi.org/10.1177/0146167214529799

Sapolsky, R. M. (2005). The Influence of Social Hierarchy on Primate Health. *Science*, *308*(5722), 648–652. https://doi.org/10.1126/science.1106477

Schreiber, A., Pilkonis, P. A., & Hallquist, M. N. (2021). Attachment style moderates effects of physiological coregulation on short-term changes in anxiety and avoidance. *Personality Disorders: Theory, Research, and Treatment*, *12*(6), 570–580. https://doi.org/10.1037/per0000472

Schwyck, M. E., Du, M., Li, Y., Chang, L. J., & Parkinson, C. (2023). Similarity Among Friends Serves as a Social Prior: The Assumption That "Birds of a Feather Flock Together" Shapes Social Decisions and Relationship Beliefs. *Personality and Social Psychology Bulletin*, 014616722211402. https://doi.org/10.1177/01461672221140269

Sciberas, C., & Fournier, M. A. (2023). Personality and Lifetime Need Frustration: A Person-Centered Perspective on Interpersonal Problems and Personality Pathology. *Social Psychological and Personality Science*, 19485506231191084. https://doi.org/10.1177/19485506231191084

Seok, D., & Doom, J. R. (2022). Adolescents' social support networks and long-term psychosocial outcomes. *Journal of Social and Personal Relationships*, *39*(12), 3775–3798. https://doi.org/10.1177/02654075221109021

Simpson, S. J., Sibly, R. M., Lee, K. P., Behmer, S. T., & Raubenheimer, D. (2004). Optimal foraging when regulating intake of multiple nutrients. *Animal Behaviour*, *68*(6), 1299–1311. https://doi.org/10.1016/j.anbehav.2004.03.003

Slobodskaya, H. R. (2021). Personality development from early childhood through adolescence. *Personality and Individual Differences*, *172*, 110596. https://doi.org/10.1016/j.paid.2020.110596

Smillie, L. D. (2013). Extraversion and Reward Processing. *Current Directions in Psychological Science*, *22*(3), 167–172. https://doi.org/10.1177/0963721412470133

Smith, K. E., & Pollak, S. D. (2021). Early life stress and perceived social isolation influence how children use value information to guide behavior. *Child Development*, cdev.13727. https://doi.org/10.1111/cdev.13727

Smolla, M., Gilman, R. T., Galla, T., & Shultz, S. (2015). Competition for resources can explain patterns of social and individual learning in nature. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1815), 20151405. https://doi.org/10.1098/rspb.2015.1405

Somerville, L. H., Haddara, N., Sasse, S. F., Skwara, A. C., Moran, J. M., & Figner, B. (2019). Dissecting "Peer Presence" and "Decisions" to Deepen Understanding of Peer Influence on Adolescent Risky Choice. *Child Development*, *90*(6), 2086–2103. https://doi.org/10.1111/cdev.13081

Somerville, L. H., Sasse, S. F., Garrad, M. C., Drysdale, A. T., Abi Akar, N., Insel, C., & Wilson, R. C. (2017). Charting the expansion of strategic exploratory behavior during adolescence. *Journal of Experimental Psychology: General*, *146*(2), 155–164. https://doi.org/10.1037/xge0000250

Sønderlund, A. L., Morton, T. A., & Ryan, M. K. (2017). Multiple Group Membership and Well-Being: Is There Always Strength in Numbers? *Frontiers in Psychology*, *8*, 1038. https://doi.org/10.3389/fpsyg.2017.01038

Surowiecki, J. (2005). *The wisdom of crowds*. Anchor.

Sutton, R. S., & Barto, A. G. (2018). *Reinforcement learning: An introduction* (2nd ed.). The MIT Press.

Thibaut, J. W., & Kelley, H. H. (1959). *The Social Psychology of Groups* (1st ed.). Routledge. https://doi.org/10.4324/9781315135007

Topel, S., Ma, I., Sleutels, J., van Steenbergen, H., de Bruijn, E. R. A., & van Duijvenvoorde, A. C. K. (2023). Expecting the unexpected: A review of learning under uncertainty across development. *Cognitive, Affective, & Behavioral Neuroscience*, *23*(3), 718–738. https://doi.org/10.3758/s13415-023-01098-0

Twenge, J. M., Haidt, J., Blake, A. B., McAllister, C., Lemon, H., & Le Roy, A. (2021). Worldwide increases in adolescent loneliness. *Journal of Adolescence*, *93*(1), 257–269. https://doi.org/10.1016/j.adolescence.2021.06.006

van de Groep, S., Meuwese, R., Zanolie, K., Güroğlu, B., & Crone, E. A. (2020). Developmental Changes and Individual Differences in Trust and Reciprocity in Adolescence. *Journal of Research on Adolescence*, *30*(Suppl 1), 192–208. https://doi.org/10.1111/jora.12459

van den Berg, Y. H. M., Lansu, T. A. M., & Cillessen, A. H. N. (2020). Preference and popularity as distinct forms of status: A meta-analytic review of 20 years of research. *Journal of Adolescence*, *84*, 78–95. https://doi.org/10.1016/j.adolescence.2020.07.010

van Dijk, E., & De Dreu, C. K. W. (2021). Experimental Games and Social Decision Making. *Annual Review of Psychology*, *72*(1), 415–438. https://doi.org/10.1146/annurev-psych-081420-110718

Van Harmelen, A.-L., Kievit, R., Ioannidis, K., Neufeld, S., Jones, P., Bullmore, E., Dolan, R., Fonagy, P., Goodyer, I., & NSPN Consortium. (2017). Adolescent friendships predict later resilient functioning across psychosocial domains in a healthy community cohort. *Psychological Medicine*, *47*(13), 2312–2322.

Vanyukov, P. M., Hallquist, M. N., Delgado, M., Szanto, K., & Dombrovski, A. Y. (2019). Neurocomputational mechanisms of adaptive learning in social exchanges. *Cognitive, Affective, & Behavioral Neuroscience*. https://doi.org/10.3758/s13415-019-00697-0

Villalonga-Olives, E., & Kawachi, I. (2015). The measurement of social capital. *Gaceta Sanitaria*, *29*(1), 62–64. https://doi.org/10.1016/j.gaceta.2014.09.006

von Salisch, M., Zeman, J., Luepschen, N., & Kanevski, R. (2014). Prospective Relations Between Adolescents' Social-emotional Competencies and Their Friendships. *Social Development*, *23*(4), 684–701. https://doi.org/10.1111/sode.12064

Wajnberg, E., Fauvergue, X., & Pons, O. (2000). Patch leaving decision rules and the Marginal Value Theorem: An experimental analysis and a simulation model. *Behavioral Ecology*, *11*(6), 577–586.

Wann, D. L., Waddill, P. J., Polk, J., & Weaver, S. (2011). The team identification–social psychological health model: Sport fans gaining connections to others via sport team identification. *Group Dynamics: Theory, Research, and Practice*, *15*(1), 75–89. https://doi.org/10.1037/a0020780

Warren, C., McGraw, A. P., & Van Boven, L. (2011). Values and preferences: Defining preference construction. *WIREs Cognitive Science*, *2*(2), 193–205. https://doi.org/10.1002/wcs.98

Wentzel, K. R., Barry, C. M., & Caldwell, K. A. (2004). Friendships in Middle School: Influences on Motivation and School Adjustment. *Journal of Educational Psychology*, *96*(2), 195–203. https://doi.org/10.1037/0022-0663.96.2.195

West, S. A., El Mouden, C., & Gardner, A. (2011). Sixteen common misconceptions about the evolution of cooperation in humans. *Evolution and Human Behavior*, *32*(4), 231–262. https://doi.org/10.1016/j.evolhumbehav.2010.08.001

Wiggins, J. S. (1991). Agency and communion as conceptual coordinates for the understanding and measurement of interpersonal behavior. In *Thinking clearly about psychology: Essays in honor of Paul E. Meehl, Vol. 1: Matters of public interest; Vol. 2: Personality and psychopathology.* (pp. 89–113). University of Minnesota Press.

Xu, Y., Harms, M. B., Green, C. S., Wilson, R. C., & Pollak, S. D. (2023). Childhood unpredictability and the development of exploration. *Proceedings of the National Academy of Sciences*, *120*(49), e2303869120. https://doi.org/10.1073/pnas.2303869120

Zingora, T., Stark, T. H., & Flache, A. (2020). Who is most influential? Adolescents' intergroup attitudes and peer influence within a social network. *Group Processes & Intergroup Relations*, *23*(5), 684–709. https://doi.org/10.1177/1368430219869460

Figure 1. Repeated Sampling of Interactions Within a Group Fosters Forming Individual Bonds that Afford Valuable Resources in Adolescence
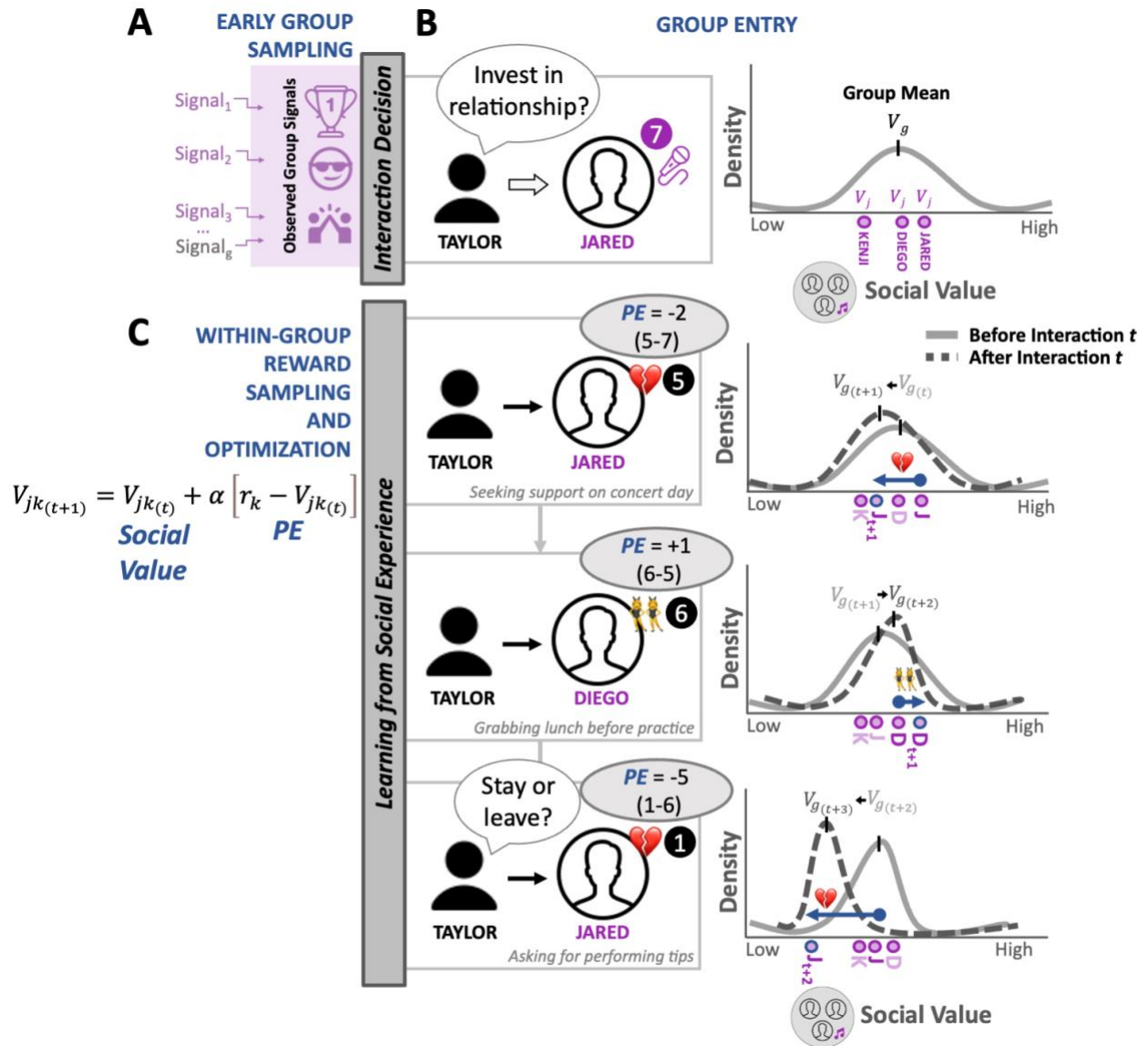
An adolescent faced with a new environment (A) first identifies the rock band as a potential social group they would like to join based on observed group signals (*early group sampling*). (B) After auditioning to make the band (*group entry*), the adolescent decides to explore new bonds with various group members to learn about the unique resources (r_k, e.g., support before concert day) afforded by group membership (V_g, group social value) and individual bonds (V_j, individual social value). (C) Through repeated interactions within the group, the adolescent learns to preferentially form bonds with the members who provide preferred resources (e.g., Diego) and adjusts future relationship investment based on social experiences that were better than expected (positive prediction error, PE) or worse than expected (negative PE) (*within-group reward sampling and optimization*). Repeated sampling of worse than expected social experiences within the band (PEs-, e.g., Jared) lowers both the social value of individual bonds and group membership, prompting decisions about whether to stay in the band or explore other groups altogether.

Figure 2. Balancing Memberships across Multiple Groups Maximizes Access to Valuable Social Capital Resources in Adolescence
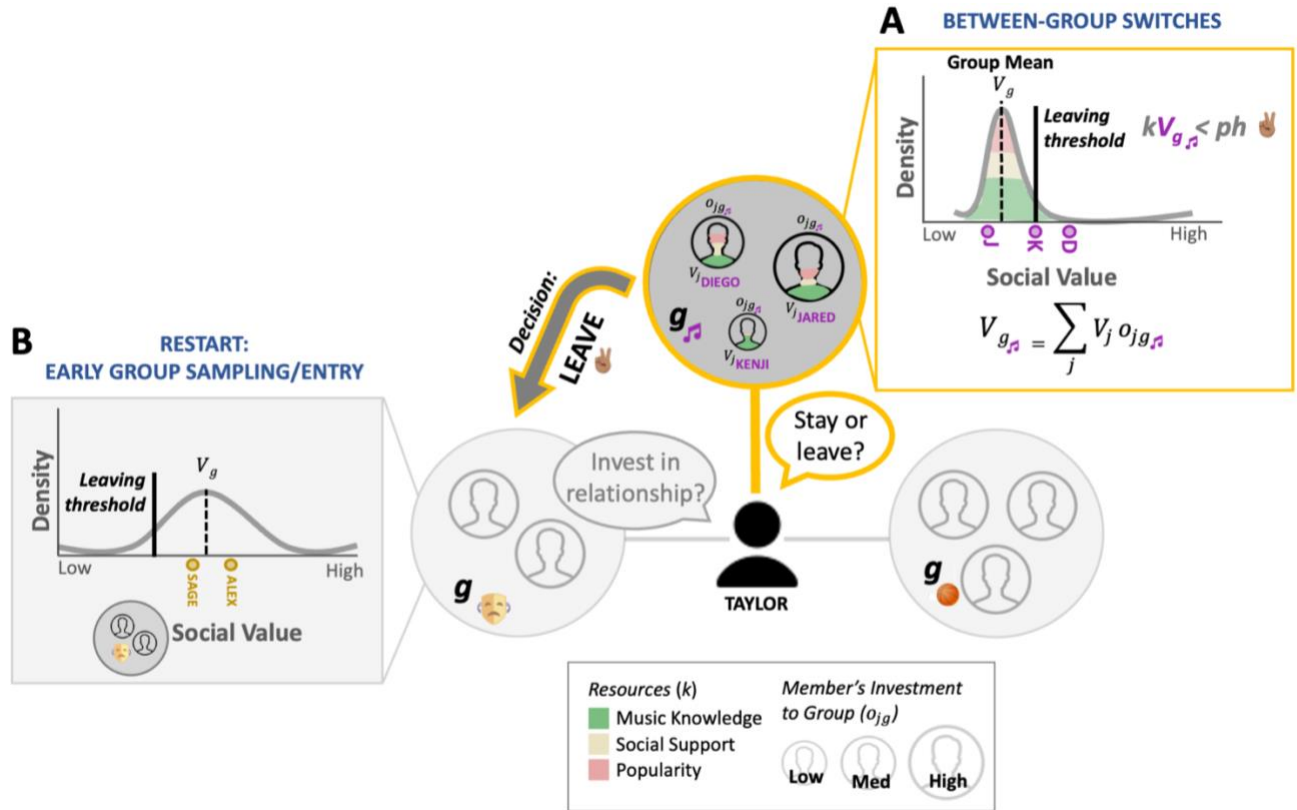
Adolescents use a mixed policy of value-based learning to resolve the social explore-exploit dilemma by balancing memberships across multiple groups that provide valuable resources. (A) The overall reward rate of investing in the rock band, V_g, is defined by the social value estimates of group members, V_j, and their estimated investment to the group, o_{jg}. Adolescents may disengage from the group if repeated sampling of negative social experiences within the band devalue the group's overall reward rate (*between-group switches*). (B) An adolescent will leave the rock band in search of potentially better alternatives (e.g., drama group) when the group-related rewards drop below the long-run social capital resources afforded over time ($kV_g < ph$) (*restart early group sampling/entry with drama group*).

Table 1. Glossary of Key Terms

Term	Definition
Explore-exploit decision-making	The balance between sampling unfamiliar options with the goal of discovering higher value (exploration) and choosing options with known high value (exploitation)
Interpersonal circumplex	Conceptual model that describes two orthogonal dimensions of social behavior: (1) agency and (2) affiliation. Agentic goals reflect the extent to which individuals attain status, influence, and power in social interactions, while communal goals reflect the attainment of closeness, cooperation, and affiliation.
Marginal value theorem (MVT)	Computational account of how long organisms forage in each resource patch to maximize rewards. In MVT, the expected rewards of a patch, learned from experience, is compared to the average rewards expected elsewhere and guides patch staying/leaving
Mature social competence	Developing the social knowledge and skills to be capable of functioning independently from adults
Prediction error (PE)	Difference between obtained and prior expected reward
Reinforcement learning (RL)	Computational account of how organisms adapt their behavior to maximize rewards. In RL, the expected value of stimuli or actions learned from experience guides approach/avoidance. Learning is driven by how unexpected the outcome is
Reward sensitivity	Processing and responding to pleasurable and/or reinforcing stimuli
Social capital	Networks and relationships—and the norms of reciprocity and trustworthiness that arise from them—that facilitate cooperation and collective action for mutual benefit within a community
Social flexibility	The ability to adapt one's social behaviors, motivations, and goals in response to changing social contexts
Social resources (k)	Tangible knowledge, skills, and rewards embedded in social bonds and networks
Social value (V)	Expected reward derived from bonds among individuals (V_j) and groups (V_g)

Table 2. Components and Predictions of Formal Model of Social Explore-Exploit Decision-Making in Adolescence

Components of Social Explore-Exploit Decision-Making	Mathematical Formalization	Example Hypotheses
Within-Group Bond Valuation		
How Does an Adolescent Learn the Social Value of a Given Group? *"group reward sensitivity"*	$$V_g = \sum_j V_j\, o_{jg}$$ V_g = expected group value V_j = expected individual value o_{jg} = individual's investment to the group	Adolescents will value groups in proportion to their valuation of individuals in those groups. Moreover, this relationship will depend on how much group members are seen to be invested in the group
How Does an Adolescent Learn the Social Value of a Given Person Within a Social Group? *"individual reward sensitivity"*	$$V_j = \sum_k V_{jk}\, P_k$$ V_j = expected individual value V_{jk} = tangible resources provided by individual P_k = adolescent's preference for specific resources	Within a group, adolescents will value members who provide preferred resources
How Does an Adolescent Update their Social Value Estimate of a Group Member Based on Social Experience? *"social flexibility"*	$$V_{jk}(t+1) = V_{jk}(t) + \alpha\left[r_k - V_{jk}(t)\right]$$ α = learning rate, extent to which social feedback influences updated individual value $r_k - V_{jk}(t)$ = prediction error, discrepancy between expected and obtain outcomes t = each interaction	For a given adolescent, experiencing social rejection from a group member will lead to a downward adjustment of their individual valuation
How Does an Adolescent Decide with Whom to Interact? *"social exploration policy"*	*Hypothesis 1 (two-step choice):* $$p(j \in g) = \frac{e^{V_{j \in g}}/\beta}{\sum_{m \in g} e^{V_m}/\beta}$$ $$p(g) = \frac{e^{V_g}/\beta}{\sum_i e^{V_{G_i}}/\beta}$$ *Hypothesis 2 (one-step choice):* $$p(j) = \frac{e^{V_j}/\beta}{\sum_m e^{V_m}/\beta}\, g_j$$	In early stages of social-exploit dynamics within a new group, adolescents will typically exploit existing bonds with members whom they value most highly, yet they will also explore other group members to compare their social values for deciding the direction of their future social interactions

	β = temperature, tendency for stochastic exploration V_m = expected value of all possible individuals with whom the adolescent could interact V_{G_i} = expected value of all groups g_j = homophily bias, extent to which group membership overlap constrains interaction choice	Adolescents will be less likely to interact with socially distant people (low homophily bias), even if they consider them valuable
Between-Group Switches		
How does an Adolescent Decide Whether to Stay in a Given Group *G* or Invest in Other Groups Altogether? *"group switches"*	$$kV_g > ph$$ k = local depletion rate, extent to which group's value diminishes with time V_g = expected group value p = overall rewards available in environment h = opportunity cost of time	Adolescents will be more likely to switch to a new group when their current group offers lower value resources than the average of alternative groups